PB89-189732

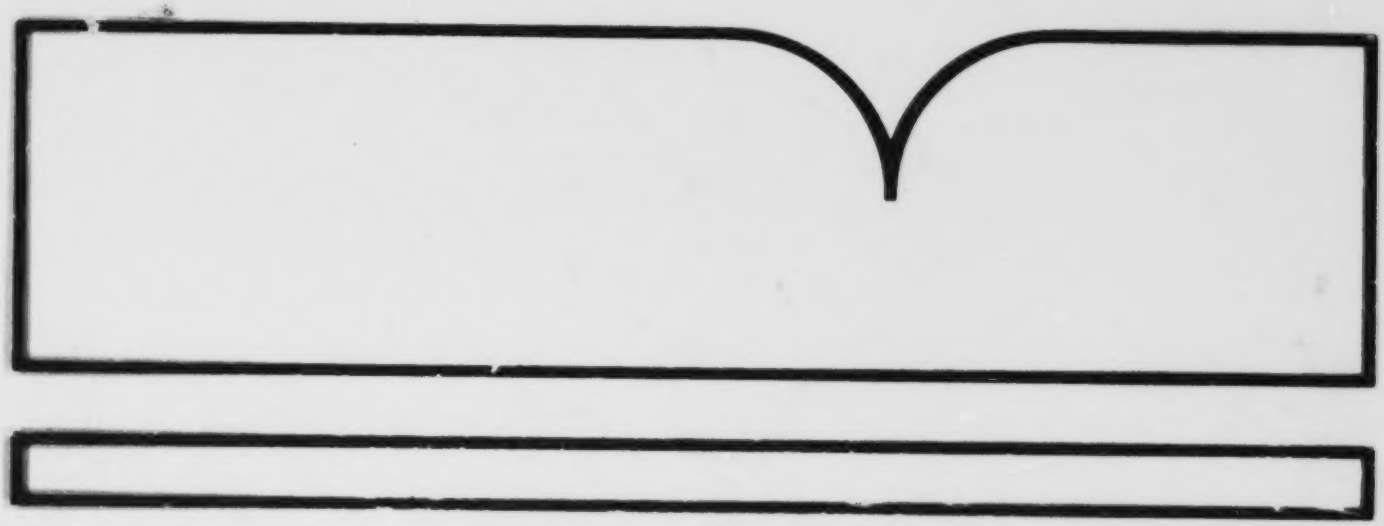
Pesticides and Wetlands Overseas
A Framework for Mitigating Adverse Impacts

California Univ., Berkeley

Prepared for:

Environmental Protection Agency, Washington, DC

20 Nov 87



U.S. Department of Commerce
National Technical Information Service
NTIS

PESTICIDES AND WETLANDS OVERSEAS:

A FRAMEWORK FOR MITIGATING ADVERSE IMPACTS

Gretta Goldenman

Graduate School of Public Policy
University of California, Berkeley

The author conducted this study during a summer internship with the U.S. Environmental Protection Agency's National Network for Water Policy Research and Analysis (NNWPRA) pilot project. The judgments and conclusions are not necessarily endorsed by the School, the University, or the Agency who facilitated this study.

November 20, 1987

50272 - 101

REPORT DOCUMENTATION PAGE	1.REPORT NO. 600/9-89/014	2.	PB89-189732

4. Title and Subtitle
Pesticides and Wetlands Overseas:
A Framework for Mitigating Adverse Impacts

5. Report Date
Completed Fall 1988

6.

7. Author(s)
Gretta Goldman, Graduate Student

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
University of California (Berkeley)
Graduate School of Public Policy
2607 Hearst Ave.
Berkeley, CA 94720

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C)
(G)

12. Sponsoring Organization Name and Address
U. S. Environmental Protection Agency
Office of Cooperative Environmental Management
499 South Capitol Street, SW A101-F6
Washington, DC 20460

13. Type of Report & Period Covered
Technical Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

2303 PESTICIDES AND WETLANDS OVERSEAS: A FRAMEWORK FOR MITIGATING ADVERSE IMPACTS

This project is part of the National Network for Environmental Management Studies (NNEMS) under the auspices of the Office of Cooperative Environmental Management of the U. S. Environmental Protection Agency. Wetland destruction and pesticide misuse are examples of environmental problems that have been exacerbated by economic development at the expense of the environment. This study looks at the pesticide-affected wetlands and reviews the scientific literature to determine some preliminary steps toward devising effective policies for safeguarding wetlands in developing countries from pesticides-related harm. The study discusses three case studies as well as the physical and chemical interactions, the biological interactions, and policy options.

Pesticides can enter wetlands through direct spraying, as in vector control, or indirectly, through agricultural runoff, industrial contamination, or airborne deposition. A valuable function of wetlands is the ability to act as a sink for hazardous chemicals. Conversely, chemicals can overload a wetlands' ability to break down pollutants and adversely affect the biota of a wetland ecosystem. In looking at how pesticides affect fragile ecosystems like wetlands, it is important to assess both acute and long-term impacts.

17. Document Analysis a. Document Descriptors

b. Identifier's/Open-Ended Terms

c. COSATI Field/Group

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL INFORMATION SERVICE
SPRINGFIELD, VA. 22161

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
	Unclassified	76
	20. Security Class (This Page)	22. Price
	Unclassified	D01595/MF 6.95

(See ANSI-Z39.18)

Disclaimer

This report was furnished to the U. S. Environmental Protection Agency by the graduate student identified on the cover page, under a National Network of Environmental Policy Studies fellowship.

The contents are essentially as received from the author. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention, if any, of company, process, or product names is not to be considered as an endorsement by the U. S. Environmental Protection Agency.

EXECUTIVE SUMMARY

Overview: Wetland destruction and pesticide misuse are examples of environmental problems that have been exacerbated by economic development at the expense of the environment. This study looks at pesticide-affected wetlands and reviews the scientific literature to determine some preliminary steps towards devising effective policies for safeguarding wetlands in developing countries from pesticide-related harm.

Pesticides can enter wetlands through direct spraying, as in vector control, or indirectly, through agricultural runoff, industrial contamination, or airborne deposition. A valuable function of wetlands is the ability to act as a sink for hazardous chemicals. Conversely, chemicals can overload a wetland's ability to break down pollutants and adversely affect the biota of a wetland ecosystem. In looking at how pesticides affect fragile ecosystems like wetlands, it is important to assess both acute and long-term impacts.

Case Study #1 -- Orchard Drainage Ditch: After 20 years of extensive pesticide exposure, a ditch in West Germany had decreased in species diversity. Seven insect orders showed decreases in abundance, with only one insect order (Diptera) showing a significant increase in species diversity and abundance. The study concluded that the application of pesticides had stressed and distorted the orchard drain habitat in ways that made conditions more conducive to some species than others.

Case Study #2 -- African Trypanosomiasis: Africa's tsetse fly control programs utilize aerial spraying to apply insecticides to vast areas of tsetse habitat, such as shrubs on floodplains and thickets bordering waterways. Widespread animal and fish kills are no longer common with ultra-low volume (ULV) application methods, but species reduction remains a concern. Pesticides restricted in industrialized countries for their environmental persistence are widely applied, including dieldrin, endosulfan, and DDT. While studies do indicate these chemicals degrade more quickly under tropical conditions, less is known about possible bioaccumulation in humans and wildlife. Tsetse fly control programs have led to expanded cattle production in many parts of Africa, resulting in extensive overgrazing.

Case Study #3 -- Rice Cultivation in Southeast Asia: Peasant-based rice cultivation evolved over centuries into a highly productive polyculture. An ecological study of a rice field in Thailand before widespread pesticide use found at least 19 different species of vegetables and animals raised or caught and used as food by local people. With the advent of fertilizer and pesticide-dependent high-yielding varieties, rice yields have increased but yields of fish, crustaceans and other protein foods have decreased. Pesticide application on rice has resulted in pest resistance and resurgence, residues on food for human consumption and reductions in species diversity.

Physical and chemical interactions: Once a pesticide enters a wetland, its environmental fate is determined by its chemistry and how it interacts with soil and water. Pesticides sorbed strongly onto soil particles may become deposited in wetland sediment. There they may degrade via chemical and biological processes into less toxic substances or they may be slowly released into overlying water, resulting in their continued bioavailability. A wetland's hydrology determines whether contaminants become concentrated or dispersed.

Biological interactions: Microorganisms in wetlands can break down environmental toxins. Conversely, contaminants may inhibit useful microbial activity, such as denitrifiers or decomposers. Pesticides can have lethal or sublethal effects on plant and animal life, with each pesticide varying in how it affects different species. Adverse impacts from pesticide contamination include destruction of habitat, interruption of food chains, bioaccumulation to toxic levels in higher species, or the weakening of native species, with the result that hardier, less desirable species invade.

Gaps in the literature: Most of the literature on environmental and health impacts of pesticides is based on laboratory studies looking at one-time exposures to individual chemicals. Less is known about the long-term impact of multiple chemicals on wetland ecosystems under field conditions. More base-line studies on wetland ecosystems in tropical climates are needed to determine food chain relationships. Screening of people and wildlife for pesticide residues might be a cost-effective way of determining bioaccumulation under tropical conditions.

Policy options: Efforts to mitigate pesticide-related harm in wetlands should approach the problem from multiple points of view. (1) Wetland protection measures can be used to designate the most valuable wetlands as pesticide-free zones and to stem sources of pesticide contamination. (2) Pesticide regulatory measures can restrict availability of chemicals that are environmentally persistent or toxic to aquatic animals and regulate pesticide application practices. (3) Integrated development measures would seek methods of encouraging economic development that sustain environmental productivity, such as agricultural methods that minimize use of chemicals. International development institutes and the U.S. Environmental Protection Agency can provide project-by-project examples of environmentally sensitive development as well as research and training assistance for developing countries.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

1.0 INTRODUCTION 1

1.1 Defining and defending wetlands 2
1.2 Paths of pesticide contamination 3
1.3 Pesticide toxicity and persistence 6

2.0 PROBLEM DEFINITION: ARE WETLANDS PESTICIDE SINKS OR RESERVOIRS? 8

3.0 PESTICIDE/WETLAND INTERACTIONS 10

3.1 Case Study #1: Orchard Drainage Ditches 10
3.2 Case Study #2: African Trypanosomiasis 12
3.3 Case Study #3: Rice Cultivation in Southeast Asia 16
3.4 Conclusions 20

4.0 POTENTIAL IMPACTS ON PHYSICAL AND CHEMICAL CHARACTERISTICS OF WETLANDS 21

4.1 Substrate 22
4.2 Suspended particulates/turbidity 22
4.3 Water 24
4.4 Current patterns and water circulation 25
4.4 Normal water fluctuations 25
4.5 Salinity gradients 26

5.0 POTENTIAL IMPACTS ON BIOLOGICAL CHARACTERISTICS OF WETLANDS 26

5.1 Microbiological activity 27
5.2 Threatened and endangered species 28
5.3 Fish, crustaceans, mollusks and other aquatic organisms in the food web 28
5.4 Other wildlife 31

6.0 GAPS IN THE LITERATURE 32

6.1 Recommendations for future study 33

7.0 OPTIONS FOR MITIGATING ADVERSE PESTICIDE IMPACTS OVERSEAS: CONCLUSIONS AND RECOMMENDATIONS 34

7.1 The wetland-protection approach 35
7.2 The pesticide-regulatory approach 37
7.3 The integrated-development approach 38
7.4 Options for international institutions 41
7.5 The role of the U.S. EPA 43

8.0 CONCLUSION 44

BIBLIOGRAPHY 46

APPENDICES

A Acute toxicity of some pesticides to fishes . . .

B Macrofauna in West German drainage ditches and a rice field in Northeastern Thailand . . . .

C Responses of soil invertebrates to some insecticides and agricultural management . . . .

D Insecticides that have been used on tidal marshes and representative list of adverse consequences . . . . . .

FIGURES

1. Paths of pesticide contamination 4

2. Possible distribution and fate of pesticides and their degradation products in the biosphere 7

3. Food items for human consumption obtained from a rice field in Northeastern Thailand and their food chains, with projected long-term and short-term effects from pesticides 19

4. Relative mobility of pesticides in soil 23

5. Plant uptake and translocation of pesticides from soils 29

1.0 INTRODUCTION

It is widely recognized today that economic development cannot succeed if it destroys resources needed to sustain future local or global productivity. In the industrialized countries, public awareness of the costs of environmental damage has grown to the point that conflicts between developing a natural resource and preserving it are not infequently decided in favor of preservation.

The conflict between development and environment is less well defined in most developing countries and the calculus of risks and benefits are different. Because of the pressing need to address endemic poverty and unemployment, the impetus is towards economic development at all costs. Consequently, few checks exist to halt the destruction of fragile natural ecosystems.

At the same time, the majority of people in developing countries remain directly dependent on the land for their economic survival. Halting the spread of poverty also means preserving the productivity of the environment.

This paper looks at two international environmental problems -- wetland deterioration and pesticide misuse -- which have been exacerbated by the pursuit of development at the expense of the environment. Wetlands, no matter where found in the world, are uniquely productive and hence highly valuable ecosystems. Yet they are under pressure from agricultural development, mining, roadbuilding, pollution and other human impacts.

Pesticides -- synthetic organic chemicals used to control problematic insects, plants and other biota -- have provided tangible benefits, including crop protection and control of vector-transmitted

disease. Their costs in terms of environmental damage have also been well-documented.

By looking at case studies of pesticide-affected wetlands in developing countries, this report clarifies how pesticide regulation and wetlands protection policy converge. It reviews the scientific literature on how pesticides and wetlands interact and identifies gaps in the knowledge of long-term environmental impacts of pesticides on complex ecosystems. In addition to suggesting research needs for the future, it offers a framework that might be used for developing guidelines on how to safeguard wetlands from pesticide-related harm. It also explores various policy options.

1.1 Wetlands and chemicals

Wetlands form an interface between terrestrial and aquatic ecosystems. A variety of wetland categories have been established, including saltwater ecosystems (coastal tidal flats, mangrove swamps, marine estuaries) and freshwater systems (inland estuaries, prairie potholes, bogs, etc.). Section 404(b)(1) of the Clean Water Act defines wetlands as "areas that are inundated or saturated by surface or ground water...[that] support a prevalence of vegetation typically adapted for life in saturated soil conditions."

Wetlands cover 6 percent of the world's land surface and rank among the most productive ecosystems on earth. Tidal areas provide nurseries for two-thirds of the fish caught worldwide, for instance (Maltby, 1986, p.19), and give vital shelter and support to many plant and animal species that cannot survive under other conditions.

One of the most valuable functions of wetlands is their ability to influence chemicals that flow through them (Sather and Smith, 1984,

11). Under favorable conditions, wetlands can reduce the velocity of water flow, causing polluted sediments to be deposited in wetland soils. The productivity of many wetlands can lead to high rates of uptake of contaminants by vegetation, with subsequent burial in sediment or peat accumulation when the plants die (Mitsch and Gosselink, 1986, p.404).

Water chemistry changes that occur in wetlands can influence bonding and/or dissociation of pesticides to sediments. Through chemical processes and biological decomposers, wetlands can even transform and break down many pollutants. Because of these attributes, wetlands are used by some municipalities as tertiary waste disposal systems (Odum et al, 1977).

Yet wetlands can also be imperiled by human-caused contamination. Too many chemicals may overload a wetland's ability to cope with contamination (Novotny and Chesters, 1981, p. 2121). Contaminants may affect selected organisms, interrupting food chains on which other species may be dependent, accumulating to toxic levels in higher species, or weakening native species so as to allow hardier non-native species to invade (Heckman, 1983).

1.2 Paths of Pesticide Contamination

Pesticides may enter wetlands in a number of ways, as illustrated in Figure 1. Pesticide contamination of a wetland may be deliberate and direct. A public health campaign may involve spraying a marsh or swamp with an insecticide in an effort to control a vector-transmitted disease, like malaria or trypanosomiasis. Or an aquatic herbicide may be used to clear a waterway for navigational purposes, with secondary impact on flora and fauna at water's edge.

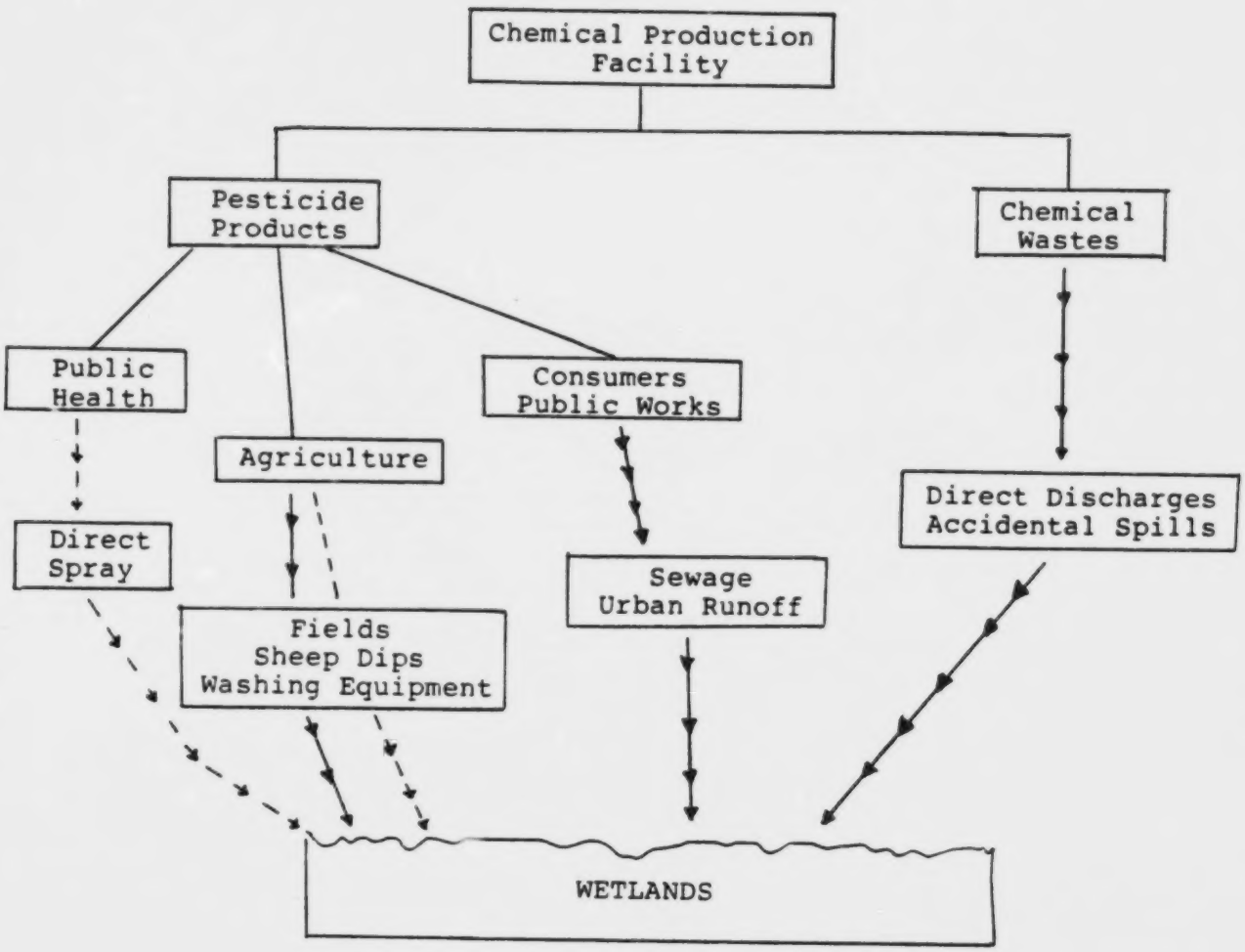


FIGURE 1: PATHS OF PESTICIDE CONTAMINATION

[Key: ◄——◄—— Waterborne; ◄- -◄- -◄ Airborne]

Pesticides have been used to kill unwanted aquatic animals, like lamprey eels or carp in North America (Heckman, 1983, p. 365). And in certain types of wetland-dependent agricultural production, such as rice or cranberry cultivation, pesticides are used widely to control weeds, insects, diseases and even crusteaceans.

Pesticide contamination may also occur indirectly. Major sources of wetland pesticide pollution have been upland pesticide manufacturing facilities discharging untreated chemical waste (Merkle and Bovey, 1974; Thompson and Edwards, 1974). Another principal source is the widespread use of chemicals in modern agricultural production (Merkle and Bovey, 1974). Sewage and nonpoint runoff from urban areas are an additional source of wetland pollution.

Pesticides may also arrive at a wetland through atmospheric deposition, as vapor, wind-blown contaminated dust particles or dissolved in rainwater or snow (Slater, 1981; Peakall, 1976). A study of organochlorine residues found in Spain´s Donana National Park concluded that airborne dispersion of pesticides was more involved than surface runoff (Baluja, 1985). Levels of toxaphene in rainfall over a South Carolina salt marsh peaked during the season of heaviest agricultural use (Harder et al., 1980, 142).

Other largely unmonitored sources of contamination in aquatic ecosystems include careless use of chemical dips for control of animal parasites and dumping of empty pesticide containers. In Iran, for example, washing of pesticide spray equipment was found to be a source of organochlorine contamination. (Soedergren, 1978).

1.3 Pesticide toxicity and persistence

When surveying the impacts of pesticides on the environment, it is important to remember that the term covers hundreds of synthetic organic chemicals developed with the intent of killing an unwanted organism, whether an insect, rodent, larva, or plant. Each pesticide's chemistry, and how it interacts with soil and water, determines its environmental fate once it enters a wetland. Just as chemical characteristics vary from pesticide to pesticide, so are there variances in the ways in which each pesticide affects different plant and animal species. Both acute and long-term effects are important to assess in looking at the impact of pesticides on complex ecosystems such as wetlands.

Pesticides are commonly grouped according to their chemical characteristics. The organochlorines (or hydrocarbonated chlorines) include DDT, aldrin, dieldrin, heptachlor, lindane, BHC, chlordane and others. Because of their dogged persistence in the environment, they have been closely studied over the past decades.

Organophosphates (parathion, guthion, mevinphos, etc.) and carbamates (aldicarb, carbaryl) tend to biodegrade more quickly than the organochlorines, but this relative lack of persistence means they are often applied repeatedly. Such repeated applications can lead to their accumulation in soils (Miles *et al.*, 1978). One study found residues of parathion persisting in the soil for over 16 years (Stewart *et al.*, 1971).

Some pesticides commonly regarded as less of an environmental hazard because of their relative lack of persistence are more acutely toxic than the organochlorines. The organophosphate malathion poses a particular hazard to aquatic animals, for instance. On the other

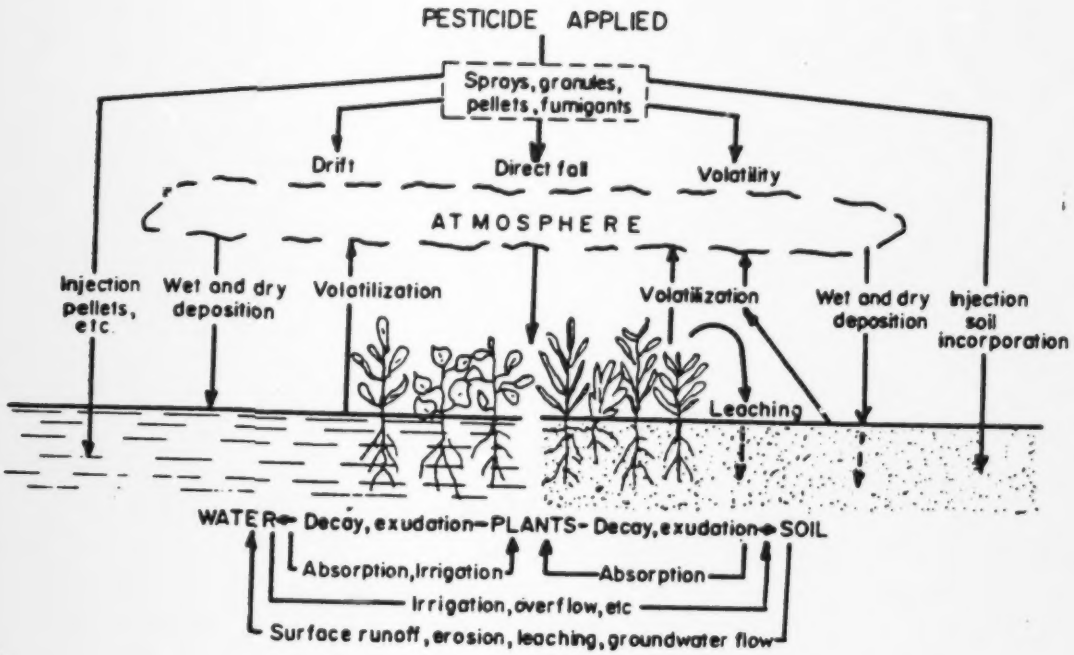


FIGURE 2: Possible distribution and fate of pesticides and their degradation products in the biosphere (from Novotny and Chesters, 1981, p. 232).

hand, the carbamates are highly toxic to insects but relatively less toxic to vertebrates, like fish (Post, 1983, 235-38). Appendix A contains selected tables giving acute toxicity of various pesticides to fish.

Pesticides in the environment break down when chemical or biological activity convert the original compound to other products. Figure 2 provides a schematic illustration of how pesticides and their degradation products are distributed in the environment. The degradation products are generally less toxic than the original pesticide, with some notable exceptions (Baker, 1985). Aldrin, for instance, converts to dieldrin which is highly persistent in the environment.

Studies of pesticide residues in tropical environments indicate that higher temperatures, ultra-violet values and other environmental factors contribute to faster degradation of most pesticides than in temperate climates (MacLennan, 1981; Sethunathan, 1973). Others hint that pesticide residues may not have disappeared as much as simply were not found (Lichtenstein, 1980, p. 349). Given the technical limitations of carrying out accurate in situ investigations in many developing countries, underestimation of pesticide residues may not be uncommon. More study is needed, overall, to determine the environmental fate and toxicity of pesticide degradation products in tropical ecosystems.

2.0 PROBLEM DEFINITION: HOW DO PESTICIDES AFFECT WETLANDS?

This report is primarily concerned with how wetlands in developing countries can be protected from any harmful or potentially harmful

While acknowledging the relevance of that debate, this report does not undertake a resolution of the issue.

3.0 PESTICIDE/WETLAND INTERACTIONS

The case studies below were selected to illustrate the impact of long-term chronic exposure to pesticides in wetlands in developing countries.

3.1 Case Study #1: Orchard Drainage Ditches

The vast majority of chemicals used for pest control purposes today are applied agriculturally. Because most pesticide regulatory processes require data on health and environmental effects of a pesticide before it can be registered for sale and use, there is an abundance of laboratory studies looking at one-time exposures to individual chemicals. One of the few studies that investigates the impact of chronic pesticide use in an agricultural setting is a study of an orchard drainage ditch in Germany (Heckman, 1982; 1983).

The ditch was first studied in the 1950s, before chemical pesticides were in wide use in the orchard, and then again twenty years later. In the 1970s, the orchard ditch was exposed to fungicide sprays about 16 times each year, insecticides 5 time, and herbicides, acaricides and a rodenticide once each.

Counts of species present before pesticide use were compared to counts of species made two decades later. The object of the study was to ascertain if any changes in species diversity and abundance had occurred in the ensuing decades.

The most significant impact found after 20 years of exposure to a

variety of pesticides was a decrease in the number of species in seven insect orders. The only order showing significant increase in species diversity was Diptera (Heckman, 1982). A nearby ditch in a unsprayed pasture was found to have a much richer fauna than even the orchard ditch in the 1950s, including more Diptera species. Table B-1 in Appendix B provides specific data.

	Heavily sprayed orchard ditch	Unsprayed pasture ditch
Diptera species	41	36
All other insect orders	49	78

(from Heckman, 1982)

Though the proportion of Diptera among the numbers of insect species represented increased slightly, the increase in number of individuals was even more significant. Many of the species in the orchard ditches were rare in number, indicating possible migration from less thoroughly sprayed habitats.

The study concluded that, while species diversity in the orchard ditches had significantly decreased since the 1950s, abundance of some surviving species had increased. In contrast, the unsprayed habitat contained more species and none that clearly dominated other fauna. The study surmised from this that the farmer's application of pesticides stressed and distorted the orchard drain habitat in ways that made conditions more conducive to some species than others.

A U.S. study looking at the impact of apple orchard runoff in North Carolina (Penrose and Lenat, 1982, p. 385) noted mortality of fish one

day after endrin application in an upstream orchard. It concluded that repeated pesticide applications led to a loss in species diversity. The abundance of individuals in intolerant species was reduced as well. Conditions were most stressed at the data collection point located farthest downstream from the orchard runoff.

The literature is not conclusive regarding what the selective elimination of species due to chronic pesticide contamination means in terms of long-term ecosystem impact. According to Woodwell (1970), the ecological effects of a toxin such as a pesticide can be anticipated and involve "a shift away from complex arrangements of specialized species toward the generalists...away from diversity in birds, plants, and fish toward monotony; away from tight nutrient cycles toward very loose ones with terrestrial systems becoming depleted, and with aquatic systems becoming overloaded..."

Specialists conjecture that disruption to plant and animal species is indeed occurring with pesticide contamination. Until each species's role in the food chain of wildlife has been identified, however, along with its response to particular pesticides, the parameters of pesticide-caused disruption to the ecosystems of individual wetlands will remain largely unknown.

3.2 Case Study #2: Chemical Control of African Trypanosomiasis

Wetlands provide habitats for a number of disease-carrying vectors, including the *Anopheles* mosquito (malaria), the *Simulium* fly (onchocerciasis, AKA river blindness), the snails which host schistosomiasis (bilharzia), and the *Glossina* or tsetse fly (African trypanosomiasis). Many public health programs use chemical pesticides

as their primary method of controlling vector-spread disease, apparently judging the hazards of pesticide application to be outweighed by their economy and convenience. Public health use of pesticides accounts for less than 5 percent of total use worldwide (Busvine, 1977, p. 185). But because these chemicals are typically applied directly to wetlands, they have direct environmental impact on these ecosystems.

One of the most ambitious vector control programs has been the World Health Organization/Food and Agriculture Organization (WHO/FAO) sponsored program to control trypanosomiasis in Africa. Two forms of trypanosomiasis are carried and transmitted by the tsetse fly: the "sleeping sickness" which infects humans, and the debilitating "nagana" which affects livestock, primarily cattle. Indigenous wildlife carry the trypanosomes but appear immune from their effects.

Africa's tsetse belt stretches for 4 1/2 million square miles, covering rain forests as well as more arid zones in the Sahel and South Africa. Wetland-type ecosystems along the banks of streams and rivers are the preferred habitat of the slow-breeding tsetse, and the prime target in any tsetse control effort. Those tsetse which carry trypanosomes infective to humans have limited flight ranges. Disease transmission tends to be clustered around sites where a few flies can feed repeatedly on humans, such as river crossings or watering places. Control has been achieved through regrouping of villages, limited clearing of vegetation around homes and on-ground spraying of tsetse habitat. (Ormerod, 1976, p.816)

In contrast, tsetse species carrying trypanosomes infective to cattle range more widely. Efforts aimed at curbing or eliminating these tsetse must cover larger geographical areas. In past decades, chemicals have been used most frequently, either (1) through selective

groundspraying of specific habitats with a persistent residue-leaving pesticide; or (2) by widespread aerial applications.

Blanket aerial spraying has become the preferred method for tsetse control because it is more convenient and more economical. (Koeman and Takken, 1977; MacLennan, 1981; Linear, 1985). Yet it can be harsher on ecosystems than selective ground spraying, because of problems like the poisoning of non-target species, wide drift or inadvertent spraying of environmentally sensitive areas.

Methods of aerial spraying used in the early 1970s deposited high concentrations of active pesticide ingredients, causing heavy mortality in non-target species (Koemann and Takken, 1977). More recently, fixed-wing planes using ULV spray methods (ultra-low volume) achieve effective tsetse fly control using much smaller concentrations of active toxins. Acute poisonings of wildlife are reportedly no longer a grave problem (MacLennan, 1981). However, since aerial applications must be repeated several times in order to eliminate new adults emerging from the pupae stage, long-term effects on fragile ecosystems may be of more concern today than acute impacts.

DDT, dieldrin and endosulfan continue to be the primary pesticides used, each highly persistent (and widely restricted) in temperate climates. One of the largest tsetse programs, carried out under the aegis of the FAO after 1974, applied between 150,000 and 175,000 tons of active ingredients to Africa's tsetse areas (Linear, 1985).

Reports on the environmental impacts of these spraying programs conflict with each other. At least one observer finds little evidence of "significant accumulation" of DDT or dieldrin (MacLennan, 1981, p. 71-72). He cites a study showing that DDT applied in the Sudan was

biologically active for 12 months or so, compared to persistence lasting 12 years or more in U.S.-based studies.

On the other hand, a WHO/FAO study found aerial spraying of dieldrin in Nigeria associated with acute deaths of many species of insects, fish, birds, and certain mammals (bats, squirrels) (WHO/FAO, 1979, p. 51). A year later, most species had recovered due to immigration from adjacent areas. Some populations of insectivorous birds, however, had been reduced to such low levels that they had apparently become extinct locally (Koemann and Takken, 1977).

Evidence that pesticides might bioaccumulate is also inconclusive. Three years of spraying in Botswana resulted in "temporary" accumulations of endosulfan in some species of fish but "below levels of biological significance." Low-level residues of dieldrin, DDT and endosulfan found in game animals were taken to indicate that both groundspray and aerial application do not significantly contaminate the grass on which the larger animals graze (Koeman and Takken, 1977).

Some observers report that local people customarily gather and eat any animals found dead after sprayings (WHO/FAO, 1979; Linear, 1985), and that this accounts partially for the dearth of signs of mortality after extensive chemical control operations. If so, residue studies of humans living in tsetse control regions might be better indicators of bioaccumulation than residue studies based on animal tissue.

The strongest environmental criticisms of tsetse fly control programs point out that, in the past, trypanosomiasis acted as a natural ecological barrier protecting floodplains and other fragile grasslands from bovine grazers. When tsetse control programs removed the trypanosome threat, vast areas of western and southern Africa were opened up for cattle production, with virturally no means of restraint

from overgrazing (Gerster, 1986; Ormerod, 1976).

Botswana's Okavango Delta area is often cited as an example of how tsetse control has led to environmental devastation, not so much from the pesticides themselves as from the effects of a large-scale cattle production scheme financed in part by the World Bank.

Studies of pesticides used in other vector control programs report similar adverse effects on non-target organisms (Thirugnanam and Forgash, 1977; Moody et al., 1978; Abban and Samman, 1982). Appendix B lists some pesticides used on insect vectors in tidal marshes.

3.3 Case Study #3: Rice Cultivation in Southeast Asia

Paddy fields are examples of highly productive wetlands cultivated for rice, a staple food for half the earth's population and arguably the most important crop in the world. Subtropical and tropical Asia account for 90 percent of the world's rice production, with much of that rice still grown by small-scale peasant farmers, rather than in monoculture operations.

Rice cultivation evolved over hundreds of years into a complex polyculture. A 1974-75 study of a plot in Northeast Thailand, where pesticides were not yet being used, found the land served simultaneously as rice field, fish culture pond and source of edible invertebrates and vegetables (Heckman, 1979, p. 196). In all, at least 19 different species of vegetables and animals were raised or caught and used as food by local farmers. Especially important were the fish, the major source of protein for local people and as important to their health as rice.

In the last twenty years, however, major changes have taken place

in Asian rice cultivation. New rice varieties introduced by the Philippines-based International Rice Research Institute (IRRI) produced yields 3 to 5 times higher than traditional varieties, but only when large quantities of inputs -- water, fertilizers and pesticides -- were used. The new varieties also had a narrower range of pest resistance than the more diverse traditional varieties, and insect, disease and weed problems soon got out of hand.

The worst pest was the brown planthopper, a pest created by this "green revolution." With new varieties grown year-round, the brown planthopper had a continuous food supply and excessive pesticide use killed off the planthopper's natural enemies (Bull, 1982). As pests developed resistance to the chemicals in use, farmers started applying larger doses more frequently.

Studies show that pesticides applied to rice fields in this "pesticide treadmill" often killed more than the target species; fish and crustaceans were particularly sensitive to pesticides (Bull, 1982). The elimination of natural predators meant that farmers had difficulty stopping pesticide use. Among the pesticides lethal to fish that have been used in Asian rice cultivation are the organochlorines endosulfan, BHC, endrin and dieldrin, as well as carbofuran, parathion and azinphos-ethyl (Isensee, 1986; Bull, 1982).

Researchers point to rapid degradation rates of pesticides used on flooded soils in tropical climates as evidence that persistent organochlorine pesticides can be used in developing country situations even when restricted in industrialized countries (Sethunathan, 1983). Rapid degradation of pesticides still does not address the problems of acute toxicity and ecosystem stress.

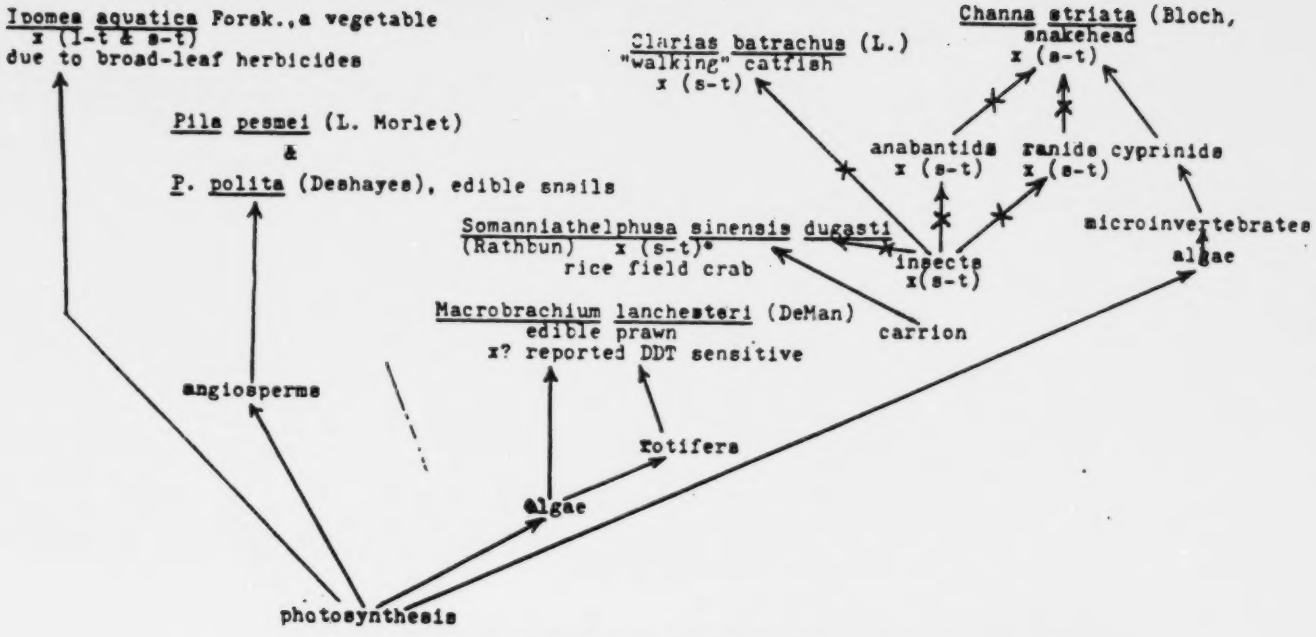
The impact of pesticides on a complex ecosystem is still not

completely understood, but the general effect, according to Heckman (1982), is to bring about a reduction in species diversity. Heckman transposed his findings from the orchard ditch study to his knowledge of rice field ecology, concluding that pesticides applied to rice fields would eliminate edible prawns and snails and greatly reduce fish productivity. Figure 3 provides a diagram of the food items produced from the rice field, together with Heckman's projections on how food productivity would be affected (see Table B-2 in Appendix B for more data.)

This conclusion is supported by a study of a spray program in Malaysia which caused a loss of important food fishes (Yunus and Lim, 1971). With the reduction in aquatic fauna, however, came improved rice yields. Increased rice production might bring profits several times larger than the cost of the insecticide, but with no fish in the paddy, the farmer could end up taking a loss (Heckman, 1982, p. 442).

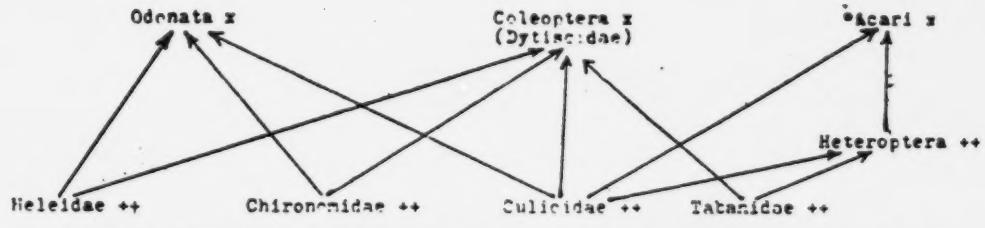
Japanese rice farmers have accumulated decades of experience in the use of pesticides on rice, learning that parathion applied to rice resulted in bird kills, pentachlorophenyl (PCP) led to shellfish and fish mortality, organo mercury compounds were taken up into the rice grain, and BHC accumulated in rice straw used for cattle fodder and eventually contaminating milk (Ishikura, 1972). Chronicles of their pesticide experiences are interesting for the insight they give into the difficulty of effectively controlling pests with chemicals while minimizing problems.

Fish not killed immediately by pesticides can concentrate the chemicals in their tissues, causing harm farther up the food chain. In the early 1970s, hundreds of people in South India -- all poor and



Food items obtained from the rice field, their food chains, and the effects to be expected from pesticides applied over the long-term (l-t) and short term (s-t). Elimination or great reduction of a group is designated (x), and all higher levels on the food chain can also be expected to be eliminated or reduced in number. The most serious loss would be *Clarias batrachus*, reported to feed largely on insects (Thakur 1978).

*Larger crabs feed on carrion ; smaller ones, chiefly on insects and other small invertebrates.



Effects of hypothetical predator elimination on a rice field biotic community over a long term. Groups eliminated or reduced in number (x) shown in their trophic relationships with groups that are expected to increase (++) as a result of decreased predation or decreased competition.

FIGURE 3: Food items for human consumption obtained from a rice field in Northeastern Thailand during 1975-1976 and their food chains, with projected long-term and short-term effects from pesticides (from Heckman, 1982, p. 438).

of low caste -- were afflicted with a mysterious, painfully crippling disease. Investigation finally determined that the disease was caused by eating pesticide-contaminated crabs scavenged from sprayed rice fields (Bull, 1982, 63).

Fish contamination and kills continue because of pesticides applied to rice lands. Farmers in Spain used an illegal pesticide to control unwanted crayfish in their rice fields, killing 30,000 birds in the process (MacKenzie, 1986). At the Tana River Delta, Kenya, plans are underway to impolder 16,000 hectares to grow rice, even though the project would reduce dry season grazing areas and the pesticides and herbicides recommended by engineers would make fish yields drop 700 tons a year (Maltby, 1986, 120).

3.5 Conclusions

The above case studies are examples of ecosystems disrupted by pesticide contamination. The orchard drainage ditch and the rice field studies illustrate how one-time and repeated applications of chemical pesticides cause stress to both plant and animal life. Individual species have different responses to this stress. Over time, highly sensitive species with adaptive characteristics unique to their specific environment may give way to hardier species. Species higher on the food chain whose natural sources of food are eliminated may also not survive. The result is, inevitably, a reduction in the number of species. This reduction may not be immediately obvious, but concern exists that the cumulative, long-term impact of pesticide use might be irrevocable -- especially for vulnerable ecosystems like wetlands.

The case study of chemical control of the African tsetse fly also

contains these elements of ecosystem disruption. Regrettably, the specific roles of the species involved, and the impact of blanket aerial sprayings on each, have not received the in-depth study of the other two ecosystems. Conflicting reports about bioaccumulation of pesticides raise concern about the implications for human exposure to pesticides moving through wetlands into the food chain.

The African tsetse campaigns raise even broader questions about the role of chemical pest control in development. Eliminating the tsetse fly as a vector has allowed commercial cattle grazing schemes to inflict another, arguably more destructive environmental disruption on the floodplains of Botswana and other African countries.

Note: In the interests of providing consistency for those reviewing the interactions between particular wetland elements and pesticides, the next two sections use the headings and subheadings of the Clean Water Act's Section 404(b)(1), Subparts C ("Potential Impacts on Physical and Chemical Characteristics of the Aquatic Ecosystem") and D ("Potential Impacts on Biological Characteristics of the Aquatic Ecosystem").

These headings and subheadings are used in the United States as the federal regulatory framework for assessing potential impacts of regulated activities on waters of the United States, including wetlands. After each subheading, potential losses of wetland environmental characteristics and values from pesticide contamination are summarized.

4.0 POTENTIAL IMPACTS ON PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE AQUATIC ECOSYSTEM

In looking at pesticide impacts, it is important to keep in mind that pesticides do not influence the physical and chemical characteristics of wetlands. Rather, the physical and chemical characteristics of wetlands affect the fate of pesticides once they enter a wetland system.

4.1 Substrate

The substrate of a wetland can be affected through (a) application of pesticides directly onto the wetland surface, as in vector control; or (b) entry of pesticides into the wetland via wind, rain, surface runoff, or streamborne water. Each pesticide's chemistry, and how it interacts with soil and water, determines its environmental fate once it enters a wetland.

Two major factors are the chemical's water solubility and its propensity to adsorb to soil particles (Schmitt, 1980; Helling, 1971). When a pesticide bonds to soil particles, its ability to move freely in the environment is reduced. See Figure 4 for relative mobility of some common pesticides. Its persistence in wetland sediment depends on the strength of the adsorption bond (Hugget, 1980).

This adsorption factor is influenced by moisture in the soil and organic matter content (Bailey, 1964). Organic matter content of sediment is reported to increase the adsorption of PCBs to sediments (Steen, 1978). Water, on the other hand, may compete with a pesticide compound for a soil adsorption site. Water added to soils containing adsorbed aldrin, dieldrin or endrin caused release of the chemicals (Weber,1972). Increasing temperatures also reversed adsorption of pesticide molecules in organic peaty soils (Schmitt, 1980).

Possible loss of environmental characteristics and values: Pesticides may absorb to soil particles and settle in wetland areas as contaminated sediment. Important factors are amount of contaminant, method of contamination (direct, indirect -- i.e., runoff), timing (one-time, chronic), persistence of pesticide, propensity to absorb and/or dissociate.

4.2 Suspended particulates/turbidity

A dynamic equilibrium exists between the amount of pesticide in solution and that adsorbed to particulate matter in suspension or in

Mobility Class[b]				
5	4	3	2	1
TCA[c]	Picloram	Propachlor	Siduron	Neburon
Dalapon	Fenac	Fenuron	Bensulide	Chloroxuron
2,3,6-TBA	Pyrichlor	Prometone	Prometryne	DCPA
Tricamba	MCPA	Naptalam	Terbutryn	*Lindane*
Dicamba	Amitrole	2,4,5-T	Propanil	*Phorate*
Chloramben	2,4-D	Terbacil	Diuron	*Parathion*
	Dinoseb	Propham	Linuron	*Disulfoton*
	Bromacil	Fluometuron	Pyrazon	Diquat
		Norea	Molinate	*Chlorphenamidine*
		Diphenamid	EPTC	Dichlormate
		Thionazin	Chlorthiamid	*Ethion*
		Endothall	Dichlobenil	*Zineb*
		Monuron	Vernolate	Nitralin
		Atratone	Pebulate	C-6989
		WL 19805	Chlorpropham	*ACNQ*
		Atrazine	*Azinphosmethyl*	*Morestan*
		Simazine	*Diazinon*	*Isodrin*
		Ipazine		*Benomyl*
		Alachlor		*Dieldrin*
		Ametryne		*Chloroneb*
		Propazine		Paraquat
		Trietazine		Trifluralin
				Benefin
				Heptachlor
				Endrin
				Aldrin
				Chlordane
				Toxaphene
				DDT

[a]Adapted from Helling et al.[41] See reference 34 for more detailed literature sources.
[b]Class 5 compounds (very mobile) to class 1 compound (immobile); in each class pesticides are ranked in estimated decreasing order of mobility.
[c]Names of pesticides are set in normal type; insecticides, fungicides, and acaricides are set in italics.

FIGURE 4: Relative mobility of pesticides in soil (from Novotny and Chesters, 1981, p. 233).

sediment. Systems with large amounts of suspended sediments may be able to absorb pesticides more readily and reduce their bioavailability to aquatic life (Lee et al, 1982).

Pesticides adsorbed in sediment may become immobilized and be buried as new sediment and organic material accretes vertically (Kadlec and Kadlec, 1979; Sather and Smith, 1984, p.14). On the other hand, pesticides adhered to such sediments may undergo slow desorption into the overlying water or get resuspended and redistributed through turbulence (Halter, 1977; Pionke, 1973). Such redistribution can prolong the bioavailability of the toxicant. According to Zitco (1980): "Sediments may be reservoirs rather than ultimate sinks and may slowly release absorbed chemicals, thus maintaining the contamination of aquatic biota for prolonged periods of time..."

Possible loss of environmental characteristics and values: Contaminated sediments, especially when resuspended via turbulence, may release a pesticide, making it again bioavailable. Timing and duration of turbulence, size of particulate matter, persistence of pesticide are factors to consider.

4.3 Water

Nicholson (1967) has observed that, sooner or later, any residues from a pesticide application will end up in water. Pesticides directly applied to water tend to remain concentrated in the water for only short periods, before the contamination is carried away by stream flow or adsorbed onto soil particles and deposited as sediment. In contrast, a single application of pesticides to a field can recontaminate a stream or wetland repeatedly through runoff, as long as residues persist (Heckman, 1983, 371).

The persistence of a pesticide in aquatic environments can be influenced by volatility (vaporization) and hydrolysis (molecular

transformation due to interaction with water). Organochlorine pesticides tend to be persistent in aquatic environments, while many organophosphates are hydrolyzed fairly rapidly (Novotny and Chesters, p. 240). Pesticide contamination can affect the life-sustaining capabilities of water, as well as its odor and taste, resulting in adverse impacts on human and other biological health.

Possible loss of environmental characteristics and values: Pesticide pollution can reduce the ability of water to support living organisms and affect human health. Water-borne pesticides can harm groups of organisms differently. Pesticides and their breakdown products can affect the odor and taste of water.

4.4 Current patterns and water circulation

Pesticides do not influence how water circulates in a wetland, but the hydrology of a wetland does affect the fate of chemicals once they enter the ecosystem in solution. If water flows act to flush concentrations from a wetland, the pesticide may disappear rapidly from both soils and water. If few drainage outlets exist for the wetland, the contaminant will tend to become more concentrated.

Ohlendorf reports an example of this phenomenon of concentration at the Kesterson Wildlife Refuge in the U.S. state of California, where the element selenium dissolved in agricultural return flows was drained into the refuge. The selenium concentrated in wetland sediment and entered the foodchain, adversely affecting wildlife (personal communication with Harry Ohlendorf, August 14, 1987).

Possible loss of environmental characteristics and values: If water flow acts to concentrate the pesticide in the wetland environment, the bioavailability of the pesticide will increase.

4.5 Normal water fluctuations

A study of water quality in the U.S. Florida Everglades found that

concentrations of pesticides in a wetland generally increased in dry seasons due to evapotranspiration and changes in precipitation (Waller, 1982). This suggests that alterations to water flows through a wetland -- for instance, an upstream dam reducing stream flow -- would tend to increase concentration of pesticides in water.

Possible loss of environmental characteristics and values: Water level changes may affect the biological sustainability of the aquatic ecosystem by altering the concentration of pesticides in the water.

4.6 Salinity gradients

Pesticide contaminants do not influence the salinity gradations of a wetland. On the other hand, factors like the salinity and pH of a soil can influence the toxicity and persistence of a pesticide (Sethunathan et al, 1975).

Possible loss of environmental characteristics and values: Salinity may increase toxicity and persistence of pesticides.

5.0 POTENTIAL IMPACTS ON BIOLOGICAL CHARACTERISTICS OF THE AQUATIC ECOSYSTEM

In contrast to the one-way impact of the physical and chemical characteristics of wetlands on pesticides, there is two-way interaction between pesticides and biota of a wetland. Pesticides do influence the biological characteristics of wetlands and some biological activity does have impact on the fate of pesticides. Some biological processes within wetlands act to mitigate adverse impacts of pesticides while other processes show great sensitivity to pesticide toxicity. Several excellent treatments of the impacts of pesticides on aquatic ecosystems are available (Hurlbert, 1975; Brown, 1978; Heckman, 1983).

5.2 Threatened and endangered species.

Pesticides may adversely affect endangered species in several ways. The application of pesticides may cause acute poisoning and mortality of endangered species. One-time or repeated exposure to pesticides or their residues can cause sublethal effects, including reproductive harm.

The use of herbicides, as in the Vietnam War, can destroy the habitat on which the species depends for shelter and food (Tschirley, 1969, 779). And the stress of pesticide contamination may disproportionately affect some species at the expense of others, as in when crucial links in the species' food chain are disrupted.

Possible loss of environmental characteristics and values: Pesticides can cause (1) mortality from acute poisoning; (2) sublethal effects from chronic pesticide or residue exposure, including reproductive harm; (3) destruction of habitat; (4) disruption of food chain on which the species is dependent.

5.3 Fish, crustaceans, mollusks and other aquatic organisms in the food web

The tendency of certain pesticides to bioaccumulate in species found at higher food chain levels is probably the most extensively documented adverse impact of pesticides on the environment. Aquatic biota are more sensitive to pesticide toxicity and appear to be able to concentrate pesticides biologically to a greater extent than terrestrial biota (Daiber, 1986, 186). This is because aquatic organisms pass water through their bodies for respiration, picking up pesticides directly from contaminated water as well as indirectly through the food chain.

Plants take up pesticides through root absorption and translocation (Nash, 1974, 268; see Figure 5). Then they become part of the wetland food chain, while living or after becoming detritus.

Insecticide	Absorbed by root	Translocated from root	Compounds found after translocation	
			Parent	Metabolites
Aldrin	Yes	Yes	Yes	Yes
Dieldrin	Yes	Yes	Yes	Probable
Isodrin	Yes	Probable	Improbable	Yes
Endrin	Yes	Yes	Yes	Yes
Heptachlor	Yes	Yes	Yes	Yes
Heptachlor epoxide	Yes	Yes	Yes	Unknown
Chlordane	Yes	Improbable	Unknown*	Unknown
Endosulfan	Yes	Yes	Yes	Unknown
Toxaphene	Probable	Improbable	Unknown	Unknown
BHC	Yes	Yes	Yes	Yes
Lindane	Yes	Yes	Yes	Yes
DDT	Yes	Probable	Probable	Yes
Diazinon	Yes	Yes	Yes	Probable
Dimethoate	Yes	Probable	Unknown	Probable
Disulfoton	Yes	Yes	Yes	Yes
Phorate	Yes	Yes	Yes	Yes
Parathion	Yes	Probable	Probable	Unknown
Chloroneb	Yes	Yes	Yes	Yes
Arsenic	Yes	Yes	Yes	--
Lead	Yes	Yes	Yes	--

* None, or has never been investigated.

FIGURE 5: Plant uptake and translocation of pesticides from soils (from Nash, 1974, p. 269).

Organochlorines are more likely to bioaccumulate in aquatic organisms, because they are highly persistent and fat-soluble, rather than water-soluble (Johnson, 1973, 196). The organophosphate pesticides are less persistent but some are acutely toxic to aquatic life.

Many environmental problems caused by pesticides arise because the chemicals are often non-specific and able to harm other species besides the original target. A study in the U.S. state of Pennsylvania could detect no macroinvertebrates or fish in a stream draining an orchard, even though maximum concentration of pesticides never lasted longer than half an hour (Truhlar and Reed, 1976, 101). A dense mat of slimy vegetation developed on the rapids below Africa's Lake Victoria: the bloom was traced to an application of DDT for vector control which had also killed grazing insects (Hynes and Williams, 1962, 331).

Pesticides do not have to kill in order to adversely affect fish or other aquatic animals (Butler, 1970, 87). Insecticide applied during a vector control program in Ghana caused behavioral changes in fish (stressed swimming, impaired escape response) that made certain species more vulnerable to capture (Abban and Samman, 1982, 245).

Mollusks are particularly sensitive to marine pollution of any kind. Pesticide contamination can make them unfit for consumption by humans or other species. Mussels have been used to monitor the presence of pesticides in aquatic environments in North America and could be the base for a global monitoring system of contaminants, particularly of the highly persistent organochlorine pesticides (Goldberg, 1986, 91).

Possible loss of environmental characteristics and values: In addition to mortality from acute poisoning, pesticide contamination can impair reproduction, growth, development, overall health and survival mechanisms of aquatic biota. This may make certain wetland species unfit for human consumption or disrupt the complex food chain of the wetland. Pesticide-caused reduction of lower trophic levels can adversely affect a wetland's overall productivity.

5.4 Other wildlife

Concentration and bioaccumulation of pesticide residues continues up the food chain to affect other wildlife dependent on wetland habitats, including birds, mammals and reptiles, with predators on the top of the food chain affected the most (Daiber, 1986, 185). In addition to acute poisonings, pesticides may affect a number of enzyme systems in wildlife, resulting in eggshell thinning in bird eggs (Peakall, 1975, 343), inhibited cholinesterase levels (Post, 1983, 236) and other impairments. Endrin used under special permit to control a widespread agricultural pest in Montana caused contamination of game birds to the point where recreational hunting had to be suspended to protect humans from consuming the birds (cite).

Possible loss of environmental characteristics and values: Pesticide contamination can disrupt the food chain on which local and transient wildlife depend. Wildlife higher on the food chain may bioaccumulate pesticide residues, resulting in impairment of reproductive and other biological functions, and making them unfit for human consumption. Animal species highly sensitive to chemicals may be displaced by less desirable species.

Note: How a developing nation monitors, mitigates or otherwise addresses each of these physical, chemical or biological interactions between wetlands and pesticides will depend largely on the specific information available in that nation. In order for a developing nation to protect the habitat of an endangered species, for example, a process must occur whereby species that are endangered are identified.

6.0 GAPS IN THE LITERATURE

Pesticides were widely introduced into agriculture and vector control before scientists became aware of the extent of their ecological impact. The literature is still catching up. Studies are available which look at pesticide/soil and pesticide/water interactions, but few look specifically at wetland impacts.

A considerable body of literature does exist on the effect of pesticides on components of aquatic environments. The majority of soil/water/pesticide studies use laboratory microcosms to determine the effect of a one-time exposure to a particular chemical. Less is known about how several pesticides might interact with each other in the laboratory, still less about multiple interactions under field conditions, and very little indeed about the long-term effects of pesticide use on natural wetland ecosystems.

The impact of pesticides on biota is well-documented in some areas, particularly the phenomenon of bioaccumulation of the more persistent pesticides in higher trophic levels in temperate climates. Studies of bioaccumulation (or lack of) under tropical conditions were not uncovered during this literature search, which could mean either that bioaccumulation is not a concern in tropical climates or that such studies are rare.

Only one in-depth ecological study was found that compared species and their populations found in a European wetland environment before and after extensive long-term pesticide use (Caspers and Heckman, 1981). No similar study was found for a developing country wetland.

Another gap found in this literature search was the lack of data on the environmental impacts of chemical production facilities

sited on or near developing country wetlands, which precluded developing a case study on such problems. The 1984 disaster at an an agricultural chemicals plant in Bhopal, India illustrated a lack of environmental safeguards in industrial processing that is widespread in developing countries (Weir, 1986). More commonly, contamination from pesticide production occurs not from a one-time disaster but from the release over time of water- or air-borne industrial wastes. An instructive example of this problem is the highly persistent contamination of sediment and biota in the St. James River, Virginia, U.S.A. Years after the kepone production plant responsible for the pollution was closed, fish and other aquatic life continued to be affected by kepone being released from contaminated sediment. (Hugget and Bender, 1980)

6.1 Recommendations for further study

The above list focuses on gaps in the scientific and technical literature on pesticide/wetland interactions. In determining priorities for further study, however, it is useful to keep in mind that in many developing countries the most basic and fundamental data is often missing.

For many countries, the starting point is to identify key wetlands and then to compile a national wetlands inventory. Other basic information needed would include identification of endangered species, sites where agricultural usage or production facilities are clustered, and compilation of what pesticides are available in local markets and their international regulatory status.

Once this basic information exists, a secondary wave of research is needed. Base-line field studies of valuable wetland ecosystems in

tropical climates could help determine food chain relationships and a wetland's overall productivity, for instance.

In-depth long-term studies to assess the extent to which highly persistent organochlorines still used in developing countries are bioaccumulating in wildlife and in people would also be helpful, but studies of this type might be prohibitively expensive. Screening of people and wildlife near pesticide-contaminated wetlands might be a cost-effective way to determine impacts.

7.0 OPTIONS FOR MITIGATING ADVERSE PESTICIDE IMPACTS OVERSEAS: CONCLUSIONS AND RECOMMENDATIONS

This section considers three different approaches that could be incorporated into national regulatory mechanisms: (1) the wetland-protection approach; (2) a pesticide-regulatory approach; (3) an integrated development approach. It concludes that national regulatory mechanisms should incorporate all three approaches, for optimal effectiveness.

For each approach, suggestions for regulatory action are given. A theme throughout is the need to recognize the political and economic factors driving a wetland's deterioration or a pesticide's usage patterns. Another recurring suggestion is for public education on the economic and environmental importance of wetlands, and of pesticides.

In many developing countries, environmental protection is not given as much priority as the right of an individual or company to exploit a resource. Until a national consensus develops within a country that places adequate value on environmental integrity, the well-meaning efforts of a few civil servants to protect natural resources and ecosystems will necessarily be isolated, sporadic, and marginally

wetlands could be spared blanket spraying so that the complex webs of resident species could be maintained. Prevention and mitigation here could also mean involve stemming upland sources of contamination -- for instance, working with farmers to curb pesticide-laced runoff.

A major problem with this approach is the difficulty in enforcing "pesticide-free" zones, particularly if pesticides were being applied heavily to surrounding areas. Ecological damage from low but repeated doses of multiple pesticides is more difficult to detect than the acute impact from a single application of a very toxic pesticide, but that long-term damage may be more serious to a wetland ecosystem in terms of reduction in species diversity.

In other words, this approach does not directly address current and future patterns of pesticide use that might harm wetlands if limitations were only placed on where pesticides were used and not on what substances. Because pesticide residues can be borne via air currents over great distances, hard-to-detect contamination could still occur if pesticides were used widely outside the controlled wetland.

Examples of possible wetland protection measures:

1. Public education campaigns could build awareness of the values and functions of wetlands and encourage citizens to join in protecting them.

2. Ecologically important pesticides could be designated as pesticide-free zones.

3. Control of vectors dependent on wetland habitats would be limited to non-chemical controls or targetted groundspraying. Where blanket aerial spraying determined to be more advantageous, sections of wetland could be left untouched so resident species could repopulate themselves.

4. Curbs could be developed to prevent the siting of industrial facilities or other developments with the potential to contaminate in wetlands areas.

wetlands could be spared blanket spraying so that the complex webs of resident species could be maintained. Prevention and mitigation here could also mean involve stemming upland sources of contamination -- for instance, working with farmers to curb pesticide-laced runoff.

A major problem with this approach is the difficulty in enforcing "pesticide-free" zones, particularly if pesticides were being applied heavily to surrounding areas. Ecological damage from low but repeated doses of multiple pesticides is more difficult to detect than the acute impact from a single application of a very toxic pesticide, but that long-term damage may be more serious to a wetland ecosystem in terms of reduction in species diversity.

In other words, this approach does not directly address current and future patterns of pesticide use that might harm wetlands if limitations were only placed on where pesticides were used and not on what substances. Because pesticide residues can be borne via air currents over great distances, hard-to-detect contamination could still occur if pesticides were used widely outside the controlled wetland.

Examples of possible wetland protection measures:

1. Public education campaigns could build awareness of the values and functions of wetlands and encourage citizens to join in protecting them.

2. Ecologically important pesticides could be designated as pesticide-free zones.

3. Control of vectors dependent on wetland habitats would be limited to non-chemical controls or targetted groundspraying. Where blanket aerial spraying determined to be more advantageous, sections of wetland could be left untouched so resident species could repopulate themselves.

4. Curbs could be developed to prevent the siting of industrial facilities or other developments with the potential to contaminate in wetlands areas.

7.2 The pesticide-regulatory approach

This approach seeks to mitigate harm to wetlands caused by pesticides by restricting sources of contamination. Public education can alert farmers, consumers and others with pest control concerns about the dangers of pesticides and help to foster safer pesticide practicides when they are marketed or applied. Regulations can strive for strict control over what pesticides are available in the marketplace for general use and what pesticides might be used on or near valuable wetland areas.

A pesticide-regulatory approach could act to curb industrial discharges from pesticide manufacturing facilities. It could also control application practices, requiring targeted ground spraying instead of blanket aerial applications, for instance, and encouraging the development and use of pest-specific pesticides instead of blanket spraying, so as to minimize secondary effects. And, above all, it could encourage research and training in non-chemical pest control practices, with the goal of weaning agriculture and other enterprises from dependencies on chemicals for pest control.

Among the limits to such an approach is the difficulty in acquiring the data needed to make reasonable regulatory decisions. Even when scientific data is available, it may be considered applicable only to limited situations. For instance, persistent pesticides are severely restricted in industrialized countries, but still widely available in most third world countries on the rationale that persistent pesticides break down more quickly in tropical wetland ecosystems. Yet there is a lack of research on the bioaccumulation of these pesticides in tropical and subtropical environments, raising

a question about the wisdom of their unrestricted marketing in many developing countries.

Regulatory approaches to an environmental problem have had limited success in curbing contamination (Commoner, 1987, p. 47). Those regulatory measures that have been most effective over the past fifteen years are those that eliminate the source of pollution. The banning of DDT and other highly persistent pesticides in the industrial countries has brought about a reduction in residues of these chemicals in the environment.

Another limitation of the pesticide regulatory approach is the need for a fairly substantial regulatory apparatus in order for a nation to develop and then enforce regulations of this kind. This can be a decided obstacle in countries where resources are limited.

Examples of possible pesticide regulatory measures:

1. Public education could stress the dangers of pesticides and provide training in safer use techniques.

2. Availability of pesticides that are highly persistent in the environment could be severely limited and only specific applications allowed.

3. Pesticides acutely toxic to fish and other aquatic organisms could be restricted to prohibit their useage on or near wetland ecosystems.

7.3 The integrated development approach

Neither the wetlands-protection nor the pesticide-regulatory approach addresses the central issue of how to bring about economic development while sustaining environmental productivity. For this, an integrated strategy that views environment and development as dynamic and inter-related processes is needed.

Such an approach would focus on overall socioeconomic development patterns within a country with the goal of choosing development

strategies that would value environmental sustainability as much as short-term economic returns. The true costs of various development strategies -- including social and environmental impacts -- would reflected in any public decisionmaking about economic directions. For example, the current practice followed by many developing countries today of subsidizing agricultural chemicals, such as pesticides, would be abandoned. Instead, the costs of pesticide regulation, health care for poisoning victims, training in safe usage, environmental monitoring and cleanup, and so on would be reflected in the prices of these inputs.

Wetlands would be valued in terms of their environmental importance and their overall productivity maintained over time, not not according to what monetarily valuable resources could be extracted in the immediate present. For example, in many developing countries, wetlands have been vital sources of food, water and income for generations of indigenous peoples and rural communities. Often these traditional usages of wetlands are sustainable, supporting the regenerative capacity of the particular wetland.

If the people who benefit most directly from the wetland in its natural state have little political or economic power, however, these uses are often undervalued. And if a wetland is found to contain peat or another minable resource that holds out the promise of securing scarce foreign exchange or enriching a select group of people, political pressures to override traditional entitlements to wetland resources may be great.

With sustainability as a primary national goal, a developing country might be more inclined to resist such pressures. It would

place a higher value on multiple uses compatible with conservation of the wetlands' unique productivity, and could well determine that environmentally sound utilization of wetlands would provide greater national economic benefits over the long term.

In the same manner, sustainable development goals for agriculture would seek to maintain soil productivity and clean water, because these would be viewed not as exploitable resources but as an economic base for the future. The emphasis would be on increasing productivity via low input, non-chemical methods of agriculture which build soil fertility instead of mining it. Agricultural inputs such as pesticides would be evaluated in light of their long-term human and environmental impacts and used for plant protection only as a last resort. Intensive and sustainable intercropping producing multiple products would be valued over extensive monoculture methods producing a single crop.

A severe political constraint that impedes implementing such strategies at this time is the current lack of national and international consensus on how to achieve sustainability without sacrificing economic growth. Once again, public education is critical to build awareness of the dangers of pursuing development at the expense of the environment. National and international debate about the roles of economic development and environmental protection in determining quality of life for the majority should or be encouraged.

It is encouraging to note that discussions are now taking place within international institions over the need to integrate environmental concerns with overall development objectives. These discussions are needed to begin incorporating the concept of

sustainable development into policy and practice.

Examples of possible integrated development measures:

1. Use of costly chemical pesticides would be discouraged by removal of any economic subsidies.

2. Sustainable agricultural methods would be promoted through economic incentives, including credit, and extension trainings.

3. Economic benefits gained from control or elimination of a pest would always be balanced against long-term ecosystem damage.

4. Multiple and sustainable usages of resources, including wetlands and agricultural lands, would be encouraged over short-term mining of exhaustible resources.

5. Public education would build awareness of the need for sustainable development and stress community values of quality of life for all over short-term economic gain for a few.

7.4 Options for international institutions

In response to critiques of past development projects, both multilateral and bilateral development agencies are now exploring the tradeoffs between environment and development and seeking to avoid mistakes of the past. The World Bank, for instance, has developed a series of guidelines on environmental safeguards to be used by project officers in planning and implementing new programs.

In 1985 the World Bank, in collaboration with the U.S. Agency for International Development (USAID), released policy guidelines to govern the use of pesticides in projects in developing countries. These guidelines cover pest management, handling and application practices, and selection of pesticides. The World Bank guidelines are complementary to the recommendations in the pesticide regulatory approach section of this report in that they include warnings about the use of excessively persistent insecticides as well as those pesticides acutely toxic to fish and aquatic invertebrates.

The World Bank's 1987 operational policy on the protection and management of wildlands take an approach similar to the wetlands protection approach also outlined earlier in this report. The policy calls for protecting wildlands of special concern and details the need to prevent agricultural runoff contaminated by pesticides from entering wildlands.

In using guidelines like these for mitigating a project's pesticide-related impact on wetlands, it would be important to integrate the pesticide regulatory approach with wetland protection measures. Steps that could be taken:

(1) Assessment of a region's ecology, including value of any wetlands, relationship of species to overall ecological balance, and the pest problem concerned.

(2) Identification of ecologically valuable wetlands, and establishment of protected zones.

(3) Evaluation of possible pest control techniques, with data from ecological assessment compared to projected adverse impacts of chemical options, and with non-chemical alternatives given preference.

(4) If chemical pesticides to be used, selection of least persistent and least toxic to aquatic animals, and method of application leaving lowest concentration of bioactive contaminant.

(5) Pilot trials, with full biological and chemical monitoring of environmental impacts on wetlands.

(6) Project-wide implementation.

The next step -- actual implementation of these guidelines on a project-by-project basis -- will be much more difficult but much more critical, for the following reasons:

- Concrete demonstrations of environmental sustainability will help developing countries build the national consensus they need to protect environmental productivity.
- The first-hand experience gained while putting these policies into practice will provide valuable lessons for developing nations to build on in developing their own national policies.

nations to build on in developing their own national policies.

- The cumulative effect of having all development projects minimize their impact on the environment will build additional international momentum to protect wetlands and other fragile ecosystems.

7.5 Options for the U.S. Environmental Protection Agency

As a leading national regulatory agency in the world in the field of environmental protection, the U.S. Environmental Protection Agency can also play an important leadership role in international efforts to protect wetlands from chemical contamination. Some cost-effective ways in which the U.S. EPA's resources might be utilized:

- Sharing of research skills and data obtained through the EPA's own wetlands protection efforts, ranging from systems of assessing environmental impact and implementing measures of mitigation. For example, evaluation methodologies, such as those used to ascertain a wetland's hydrology, are well advanced in the United States and could be usefully shared.

- Transfer of technology by direct lending of expertise. The EPA could develop programs whereby its own scientists, engineers or project managers could take paid leaves of absence for the purpose of sharing their skills and experience on a case-specific basis to a developing country. Project expenses could then be covered by other institutions.

- Training of government officials from developing countries in wetland assessment and valuation techniques. The EPA could work with federal agencies, such as the Agency for International Development, already providing training for foreign nationals to develop programs specifically on wetlands.

- Enhancing public awareness of wetlands values and functions in the United States, with the secondary effect of reaching international audiences. Education of the American business community, for instance, could have a far-ranging impact.

- Sharing of regulatory lessons learned in the United States with other governments where applicable to their regulatory frameworks. Particularly useful might be case histories of successful protection efforts as well as examples of successful management techniques.

- Encouraging and cooperating with environmentally related efforts of other federal agencies, such as the U.S. Department of

Agriculture and the Peace Corps, who are in direct contact with other countries through technical programs or organizational mandates.

- Working with bilateral and multilateral agencies, like USAID and the World Bank, to establish effective and implementable guidelines for protecting wetlands from pesticide contamination.

8.0 CONCLUSION

As this paper has outlined, mitigating the harmful impacts of shortsighted development on fragile ecosystems like wetlands will require multiple approaches. Wetlands protection efforts need to be combined with pesticide regulatory controls, while overall development strategies should plan how to achieve economic growth without sacrificing environmental integrity.

These are complex regulatory decisions requiring accurate information and a great deal of wisdom. But data itself can be uncertain, and the enormity of effort required to assess individual pesticides, or to rank wetlands in order of ecological importance or productivity, can be discouraging.

For many developing countries, however, the risk of doing nothing far outweighs the risk of beginning to take control of development and environment. In most industrialized countries, pesticide use takes place in the context of a pesticide regulatory system controlling availability, advanced systems of health care, and extensive environmental oversight. In the United States, economic development efforts which might impinge on the environment are accountable to local, state and federal agencies and must comply with requirements ranging from environmental impact assessments to mitigation efforts aimed at offsetting

potential harm.

In the absence of such controls, a developing country is overly vulnerable to harmful impacts. Indeed, a developing country is often least able to bear the cost of pesticide-related harm or the destruction of a wetland on which local fisheries depend.

Thus there is a need for caution as well as speed in moving forward to protect fragile ecosystems from the impact of pesticide contamination. For example, instead of assuming that a pesticide should be freely available within its borders, a developing nation might well be justified in instituting stricter controls than an industrial country might employ. And international institutions involved in economic development might well be advised to proceed with greater care and to focus on smaller rather than large-scale projects.

At the same time, speed is of the essence. The feeling of urgency developing among environmentally concerned citizens and policymakers in the United States must be communicated to the international community, so that further environmental deterioration of the world's resources can be prevented.

BIBLIOGRAPHY

BIBLIOGRAPHY

Abban, E.K. and J. Samman. (1982) "Further Observations on the Effect of Abate on Fish Catches." Environmental Pollution, Series A, 27/4: 245-254.

Andreu-Molina, M.M., I. Legarra and A. Nunez. (1986) "Toxicity of some ricefield pesticides to the crayfish P. charkii, under laboratory and field conditions in Lake Albufera (Spain)." Journal of Environmental Science and Health (Part B), 21:6, 529-30.

Arthur, R.D., J.D. Cain and B. Barrentine. (1976) "Atmospheric levels of pesticides in the Mississippi delta." Bull. Environ. Contam. Toxicol., 15: 129.

Bailey, G.W. and J.L. White. (1964) "Review of adsorption and desorption of organic pesticides by soil colloids, with implications concerning pesticide bioactivity." J. Agric. Food Chem. 12: 324.

Baluja, F., J. Gonzalez, C. Rico and L.M. Hernandez. (1985) "Sources and transport of organochlorine compounds and heavy metals into waters of the National Park of Donana." Bulletin of Environmental Contamination and Toxicology, 35:4, 482-489.

Boucher, F.R. and G.F. Lee. (1972) "Adsorption of lindane and dieldrin pesticides on unconsolidated aquifer sands." Environ. Sci. Technol., 6: 538.

Brown, A.W.A. (1978) Ecology of Pesticides. New York: John Wiley & Sons.

Bull, D. (1982) A Growing Problem: Pesticides and the Third World Poor. Oxford: Oxfam.

Busvine, J.R. (1977) "The control of trypanosomiasis." In: Ecological Effects of Pesticides, F.H. Perring and K. Mellanby, eds. London: Academic Press, 143-150.

Butler, P.A. (1970) "The Sub-Lethal Effects of Pesticide Pollution." In: The Biological Impact of Pesticides in the Environment, J.W. Gillette, ed. Corvallis, OR: Oregon State University, Environmental Health Science Series), 87-89.

Caspers, H. and C.W. Heckman. (1981) "Ecology of orchard drainage ditches along the fresh-water section of the Elbe Estuary." Arch. Hydrobiol., Suppl.43 (Untersuch.Elb-Aestuar 4), 347-486.

Castro, T.F. and T. Yoshida. (1971) "Degradation of organochlorine insecticides in flooded soils in the Philippines." Journal of Agricultural and Food Chemistry, 19, 1168-1170.

Cloutier, J-N. et al. "Peat Adsorption of Herbicide 2,4-D from Wastewaters." Canadian Journal of Chemical Engineering, 63/2,

April 1985.

Commoner, Barry. (1987) "The Environment." The New Yorker. 6/15/87.

Cornacchia, J.W., D.B. Cohen, and G.W. Bowes. (1984) Rice Herbicides: Molinate (Ordram) and Thiobencarb (Bolero). Sacramento, CA: California State Water Resources Control Board.

Crossland, Norman O., David Bennett, Cor J. Wolff, Richard P. Swannell. "Evaluation of Models Used to Assess the Fate of Chemicals in Aquatic Systems." Pesticide Science 17, 1986, P297(8).

Curry, J.P. (1986) "Effects of management on soil decomposers and decomposition processes in grassland." In: Microfloral and faunal interactions in natural and agro-ecosystems, M.J. Mitchell and J.P. Nakas, eds. Dordrecht, Neth.: Martinus Hijhoff/Dr. W. Junk, 349-397.

Custer, T.W., E.F. Hill and H.M. Ohlendorf. (1985) "Effects on wildlife of ethyl and methyl parathion applied to California rice fields." California Fish and Game, 71:4, 220-224.

Daiber, F.C. (1986) Conservation of Tidal Marshes. New York: Van Nostrand Reinhold.

Ekanem, S.F., J.W. Avault Jr., J.B. Graves and H. Morris. (1981) "Acute toxicity of propanil, ordram and furadan to crawfish (Procambarus clarkii) when chemicals were combined and used alone." Journal of the World Maricultural Society, 12:2, 373-383.

Food and Agriculture Organization. (1977) Report on the FAO Expert Consultation on Pesticides and the Environment. Rome: FAO.

Fukunaga, K., Y. Tsukano and J. Kanazawa. "Residue analysis of orgganomercury fungicides sprayed on rice plants." In: F. Matsumara et al., eds., Environmental Toxicology of Pesticides, pp. 177-191.

Gerster, G. (1986) "Tsetse: Fly of the Deadly Sleep." National Geographic, 170:814-833.

Gill, S.S., and C.L. Yeoh. (1980) "Degradation of carbaryl in three components of the paddy-field ecosystem of Malaysia." In: Agrochemical Residue-Biota Interactions in Soil and Aquatic Ecosystems. FAO/IAEA Advisory Group. Vienna: International Atomic Energy Agency, 259-281.

Ginn, R.M. and F.M. Fisher, Jr. (1974) "Studies on the distribution and flux of pesticides in waterways associated with a ricefield-marshland ecosystem." Pesticides Monitoring Journal, 8:1, 23-32.

Goldberg, E.D. (1986) "The Mussel Watch Concept." Environmental Monitoring and Assessment, 7: 91-103.

Grant, M.A., and W.J. Payne. (1982) "Effects of pesticides on denitrifying activity in salt marsh sediments." Journal of Environmental Quality, 11/3: 369-372.

Guenzi, W.D. and W.E. Beard. (1968) "Anaerobic conversion of DDT to DDD and aerobic stability of DDT in soil." Soil Sci. Soc. Amer. Proc., 32: 522-524.

Hall, W.D., K.L. Dickson, F.Y. Saleh, and J.H. Rodgers. (1986) "Effects of Suspended Solids on the Bioavailability of Chlordane on Daphnia magna." Archives of Environmental Contamination and Toxicology, 15: 529-534.

Halter, M.T. and H.E. Johnson. (1977) "A model system to study the desorption and biological availability of PCB in hydrosoils." Aquatic Toxicology and Hazard Evaluation, ASTM STP 634, F.L. Mayer and J.L. Hamelink, eds. Philadelphia: American Society for Testing and Materials, P. 178.

Hartung, R. (1975) "Accumulation of chemicals in the hydrosphere." In: R. Hague and V.H. Freed, eds. Environmental dynamics of Pesticides. New York: Plenum Press, pp. 185-198.

Heckman, C.W. (1979). Rice Field Ecology in Northeastern Thailand. Monographiae Biologicae, 34. The Hague, Netherlands: Dr. W. Junk.

Heckman, C.W. (1981) "Long-term effects of intensive pesticide applications on the aquatic community in archard drainage ditches near Hamburg, Germany." Arch. Environ. Contam. Toxicol., v. 10, pp. 393-416.

Heckman, C.W. (1982) "Problems of Pesticide Application on Cultivated Aquatic Ecosystems." In: Wetlands: Ecology and Management, B. Gopal, R.E. Turner, R.G. Wetzel and D.F. Whigham, eds. Jaipur, India: National Institute of Ecology and International Scientific Publications, 435-445.

Heckman, C.W. (1983) "Reactions of Aquatic Ecosystems to Pesticides." In: Aquatic Toxicology, J.O. Nriagu, ed. New York: John Wiley & Sons, 355-400.

Helling, D.S., P.C. Kearney and M. Alexander. (1971) "Behavior of pesticides in soils." Adv. Agron., 23: 147.

Hiltbold, A.E. (1974) "Persistence of pesticides in soil." In: Pesticides in Soil and Water, W.D.de Guenzi, ed. Madison, Wisc.: Soil Science Society of America, 203-222.

Holden, A.V. (1973) "Effects of pesticides on fish." In: C.A. Edwards, ed. Environmental Pollution by Pesticides. London: Plenum Press, pp. 213-253.

Hugget, R.J. and H.E. Bender. (1980) "Scientific lessons taught by kepone." Proceedings of the Workshop on Agrichemicals and Estuarine Productivity. Beaufort, N. Carolina: Duke University Marine Laboratory.

Hurlbert, S.H. (1975) "Secondary effects of pesticides on aquatic

ecosystems." Residue Reviews, 57: 81-148.

Hynes, H.B.N. and J.R. Williams. (1962) "The effect of DDT on the Fauna of a Central African stream." Ann. Trop. Med. Parasitol., 56: 78-91.

Isensee, A.R. and N. Tayaputch. (1986) "Distribution of carbofuran in a rice-paddy-fish microecosystem." Bulletin of Environmental Contamination and Toxicology, 36, 763-769.

Ishikura, H. (1972) "Impact of pesticide use on the Japanese environment." In: Environmental Toxicology of Pesticides, F. Matsumura, G.M. Boush, and T. Misato, eds. New York: Academic Press, 1-32.

Kenaga, E.E. (1972) "Factors relating to bioconcentration of pesticides." In: F. Matsumara et al., eds., Environmental Toxicology of Pesticides, pp. 193-228.

Johnson, D.W. (1973) "Pesticide Residues in Fish." In: Environmental Pollution by Pesticides, C.A. Edwards, ed. London: Plenum Press.

Johnson, H.P. and J.L. Baker. (1982) "Field-to-stream transport of agricultural chemicals and sediment in an Iowa watershed: Part 1." Data base for model testing (1976-1978). NTIS Rep. PB82-254 046. Springfield, VA: National Technical Information Service.

Joint WHO/FAO Expert Committee. (1979) The African Trypanosomiases. FAO Animal Production and Health Paper 14. Rome: FAO.

Kadlec, R.H. and J.A. Kadlec. (1979). "Wetlands and Water Quality." In: Wetland Functions and Values: The State of Our Understanding, P.E. Greeson, J.R. Clark and J.E. Clark, eds. Proceedings of the National Symposium on Wetlands, Lake Buena Vista, FL. Minneapolis, MN: Am. Water Resour. Assoc., 436-456.

Kenaga, E.E. (1980) Predicted bioconcentration factors and soil sorption coefficients of pesticides and other chemicals." Ecotoxicol. Environ. Saf., 4: 16.

Kerr, S.R. and W.P. Vass. (1973) "Pesticide residues in aquatic invertebrates." In: C.A. Edwards, ed. Environmental Pollution by Pesticides. London: Plenum Press, pp. 134-180.

Koeman, J. H., and W. Takken. (1977) "The environmental impact of tsetse control operations: a report on present knowledge." FAO Animal Production and Health Paper 7. Rome: FAO, 1-44.

Koeman, J H., F. Balk and W. Takken. (1980) "The environmental impact of tsetse control operations: a report on present knowledge." FAO Animal Production and Health Paper 7, rev.1. Rome: FAO, 00.

Lawrence, R. et al. (1985) "Managing Riparian Ecosystems to Control Nonpoint Pollution." Journal of Soil and Water Conservation, 40: 87.

Lawrenz, R.W. (1985) "Response of invertebrates in temporary vernal wetlands to Altosid Sr-10 as used in mosquito abatement programs." J. Minn. Acad. Sci., 50/3: 31-34.

Lee, F.F., R.A. Jones, and F.Y. Saleh. (1982) "Environmental significance of pesticide residues associated with aquatic sediments." J. Environ. Sci. Health, Part B, 17: 409-437.

Lichtenstein, E.P. (1980) "Soil binding and fate of agrochemicals." In: Agrochemical Residue-Biota Interactions in Soil and Aquatic Ecosystems. Vienna: International Atomic Energy Agency, 251-257.

Linear, Marcus. (1985) "The Tsetse War." The Ecologist, 15/2: 27-35.

Livingstone, R.G., N.P. Thompson, and D.A. Meeter. (1978) "Long term variation of organochlorine residues and assemblages of epibenthic organisms in a shallow north Florida estuary." Marine Biology 46: 355-372.

MacKenzie, D. (1986) "Crawfish pesticide decimates Spanish birds." New Scientist, 112: 1530, p.24.

MacLennan, K.J.R. (1981) "Tsetse-transmitted trypanosomiasis in relation to the rural economy in Africa. Part II. -- Techniques in use for the control or eradication of tsetse infestations." In: African animal trypanosomiasis: selected articles from the World Animal Review. FAO Animal Production and Health Paper 37. Rome: FAO, 65-75.

Maltby, E. (1986) Waterlogged Wealth: Why Waste the World's Wet Places? London: International Institute for Environment and Development.

Matsumura, F., G.M. Boush and T. Misato, eds. (1972) Environmental Toxicology of Pesticides. New York: Academic Press.

Matsumura, F. (1974) "Microbial degradation of pesticides." In; M.A.Q. Khan and J.P. Bederka, Jr., eds. Survival in Toxic Environments. New York: Academic Press, pp. 129-154.

McElroy, A.D., S.Y. Chiu, J.W. Nebgen, A. Aleti, and A.E. Vandegrift. (1975) "Water pollution from nonpoint sources." Water Res, 9: 675.

Merkle, M.G. and R.W. Bovey. (1974) "Movement of Pesticides in Surface Water." In: Pesticides in Soil and Water, W.D. Guenzi, ed. Madison, WI: Soil Science Society of America, 99-106.

Meyers, S.P., R.P. Gambrell, and J.W. Day, Jr. (1982) Determination of the Environmental Impact of Several Substitute Chemicals in Agriculturally Affected Wetlands. Springfield VA: National Technical Information Service PB82-242017.

Miles, J.R.W. (1980) "Adsorption of insecticide residues -- importance in environmental sampling and analysis." In: Hydrocarbons

a nd halogenated hydrocarbons in the aquatic environment, B.K. Afghan and D. Mackay, eds. New York: Plenum Press, 81.

Miranowski, John A. "Agricultural Impacts on Environmental Quality." Water Resources Research: Problems and Potentials for Agriculture and Rural Communities (Soil Conservation Society of America report), 1983, P117(8).

Mitsch, W.J. and J.G. Gosselink. (1986). Wetlands. New York: Van Nostrand Reinhold.

Moody, R.P., R. Greenhalsh, L. Lockhart, and P. Weinberger. (1978) "The fate of fenitrothion in an aquatic ecosystem." Bull. Environ. Contam. Toxicol., 19: 8-14.

Murty, A.S. (1986) Toxicity of Pesticides to Fish, Vol. I. Boca Raton, Fla: CRC Press, Inc.

Nash, R.G. (1974) "Plant uptake of insecticides, fungicides, and fumigants from soils." In: Pesticides in Soil and Water, W.D. Guenzi, ed. Madison, Wisc: Soil Science Society of America, 257-313.

Nicholson, H.P. (1967) "Pesticide pollution control." Science, 158, 871.

Novotny, V. and G. Chesters. (1981) Handbook of Nonpoint Pollution: Sources and management. New York: Van Nostrand Reinhold.

Nriagu, J.O., ed. (1983) Aquatic Toxicology. New York: John Wiley & Sons.

Odum, H.T. et al. (1977) "Recycling treated sewage through cypress wetlands in Florida." In: Wastewater Renovation and Reuse, F.M. D'Itri, ed. New York: Marcel Dekker, 35-67.

Office of Technology Assessment. (1984) Wetlands: Their Use and Regulation. Washington, D.C.: U.S. Congress, OTA-O-206.

Ormerod, W.E. (1976) "Ecological effect of control of African Trypanosomiasis." Science, 191: 815-821.

Peakall, D.B. (1976) "DDT in rainwater in New York following application in the Pacific North-West." Atm. Environ., 10:899.

Penrose, D.L. and D.R. Lenat. (1982) "Effects of apple orchard runoff on the aquatic macrofauna of a mountain stream." Arch. Environ. Contam. Toxicol., 11: 383.

Pionke, H.B. and G. Chesters. (1973) "Pesticide-sediment-water interactions" J. Environ. Quality, 2: 29-45.

Post, G.W. (1973) Textbook of Fish Health. Neptune City, NJ: T.F.H. Publications.

Premazzi, G. (1984). "Evaluation of the Impact of Malathion on the

Aquatic Environment." European Applied Research Reports, 2/2.

Richards, D.J. and Shieh, W.H. (1986) "Biological fate of organic priority pollutants in the aquatic environment." Water Research (G.B.), v. 20, pp. 1077.

Ross, L.J. and R.J. Sava. (1986) "Fate of Thiobencarb and Molinate in Rice Fields." Journal of Environmental Quality, 15:220.

Saad, Massoud A., et al. (1985) "Metals and Chlorinated Hydrocarbons in Surficial Sediments of Three Nile Delta Lakes, Egypt." Water, Air and Soil Pollution, 24/1, p. 27.

Schmitt, D.J. and P.V. Winger. (1980) "Factors controlling the fate of pesticides in rural watersheds of the lower Mississippi River alluvial valley." Trans. 45th N. Am Wildl. Nat. Res. Conf. Washington, D.C.: Wildlife Management Institute, p. 354.

Service, M.W. (1977) "Some problems in the control of malaria." In: Ecological Effects of Pesticides, F.H. Perring and K. Mellanby, eds. London: Academic Press, 143-150.

Sethunathan, N. (1973) "Microbial degradation of insecticides in flooded soil and in anaerobic cultures." Residue Reviews, 47: 143-167.

Sethunathan, N., R. Siddaramappa, T.K. Siddarame Gowda and K.P. Rajaram. (1975) "Pesticide residue problems in flooded rice ecosystems." Impact Monitoring of Residues from the Use of Agricultural Pesticides. FAO/UNEP Expert Consultation. Rome: FAO, 51-60.

Sethunathan, N., Sudhakar-Barik, K. Venkateswarlu, P.A. Wahid, C. Ramakrishna, S.S. Pal, R.C. Ray, K. Chendrayan, Y.R. Rao, V.R. Rao, T.K. Adhya. (1980) "Effects of combined pesticides application on their persistence in flooded rice soils."

Sharom, M.S., J.R.W. Miles, D.R. Harris, and F.L. McEwen. (1980) "Behavior of 12 insecticides in soil and aqueous suspensions of soil and sediment." Water Res., 14, 1095.

Shires, S.W., and D. Bennett. "Contamination and Effects in Freshwater Ditches Resulting from an Aerial Application of Cypermethrin." Ecotoxicology and Environmental Safety, 9/12, April 1985.

Singh, G. et al. (1985) "Persistence of aldrin in flooded soil under the cover of rice." Ecotoxicology and Environmental Safety, 24:1, 27.

Slater, R.M. and Spedding, D.J. (1981) "Transport of dieldrin between air and water." Arch. Environ. Contam. Toxicol., 10: 25-30.

Soedergren, Al, R. Djirsarai, M. Gharibzadeh, and A. Moinpour. (1978) "Organochlorine residues in aquatic environments in Iran, 1974." Pesticide Monitoring Journal, 12, 81.

Sonzogni, W.D., G. Chesters, D.R. Coote, D.N. Jeffs, J.C. Konrad, R.C. Ostry and J.B. Robinson. (1980) "Pollution from land runoff." Environ. Sci. Technol., 14, 148.

Spain, J.C., P.H. Pritchard, and A.W. Bourquin. (1980) "Effects of adaptation on biodegradation rates in sediment/water cores from estuarine and freshwater environments." Applied and Environmental Microbiology, 40/4: 726-734.

Steen, W.D., D.F. Paris, and G.L. Baughman. (1978) "Partitioning of selected polychlorinated biphenyls to natural sediments." Water Res, 12, 655.

Thirugnanam, M. and A. J. Forgash. (1977) "Environmental impact of mosquito pesticides: toxicity and anticholinesterase activity of chlorpyrifos to fish in a salt marsh habitat." Arch. Environ. Contam. Toxicol., 5/4: 415-25.

Thompson, A.R. and C.A. Edwards. (1974) "Effects of Pesticides on Non-Target Invertebrates in Water and Soil." In: Pesticides in Soil and Water, W.D. Guenzi, ed. Madison, WI: Soil Science Society of America, 341-386.

Truhlar, J.F. and Reed, L.A. (1976) "Occurrence of pesticide residues in four streams draining different land-use areas in Pennsylvania, 1969-71." Pesticide Monitoring Journal, 10: 101-105 (?).

Tschirley, F.H. (1969) "Defoliation in Vietnam." Science, 163: 779-786.

Tsukano, Y. (1986) "Transformation of selected pesticides in flooded rice-field soil: a review." Journal of Contaminant Hydrology, 1: 47.

U.K. Centre for Overseas Pest Research. (1975). "Environmental problems associated with the use of pesticides to control certain disease vectors and pests of livestock." In: FAO/UNEP Expert Consultation on Impact Monitoring of Agricultural Pesticides. Rome: FAO, 61-76.

Waller, B.G. Water-Quality Characteristics of Everglades National Park, 1959-77, With Reference to the Effects of Water Management. Springfield, VA: National Technical Information Service PB82-228941.

Wauchope, R.D. (1978) "The pesticide content of surface water draining from agricultural fields -- a review." J. Environ. Qual., 7:459.

Weber, J.B. (1972) Interaction of organic pesticides with particulate matter in aquatic and soil systems." In: Fate of Organic Pesticides in the Aquatic Environment, S.D. Faust, ed. Washington DC: American Chemical Society, 55.

Weir, D. (1986) The Bhopal Syndrome: Pesticide Production and the Third World. Penang, Malaysia: International Organization of

Sonzogni, W.D., G. Chesters, D.R. Coote, D.N. Jeffs, J.C. Konrad, R.C. Ostry and J.B. Robinson. (1980) "Pollution from land runoff." Environ. Sci. Technol., 14, 148.

Spain, J.C., P.H. Pritchard, and A.W. Bourquin. (1980) "Effects of adaptation on biodegradation rates in sediment/water cores from estuarine and freshwater environments." Applied and Environmental Microbiology, 40/4: 726-734.

Steen, W.D., D.F. Paris, and G.L. Baughman. (1978) "Partitioning of selected polychlorinated biphenyls to natural sediments." Water Res, 12, 655.

Thirugnanam, M. and A. J. Forgash. (1977) "Environmental impact of mosquito pesticides: toxicity and anticholinesterase activity of chlorpyrifos to fish in a salt marsh habitat." Arch. Environ. Contam. Toxicol., 5/4: 415-25.

Thompson, A.R. and C.A. Edwards. (1974) "Effects of Pesticides on Non-Target Invertebrates in Water and Soil." In: Pesticides in Soil and Water, W.D. Guenzi, ed. Madison, WI: Soil Science Society of America, 341-386.

Truhlar, J.F. and Reed, L.A. (1976) "Occurrence of pesticide residues in four streams draining different land-use areas in Pennsylvania, 1969-71." Pesticide Monitoring Journal, 10: 101-105 (?).

Tschirley, F.H. (1969) "Defoliation in Vietnam." Science, 163: 779-786.

Tsukano, Y. (1986) "Transformation of selected pesticides in flooded rice-field soil: a review." Journal of Contaminant Hydrology, 1: 47.

U.K. Centre for Overseas Pest Research. (1975). "Environmental problems associated with the use of pesticides to control certain disease vectors and pests of livestock." In: FAO/UNEP Expert Consultation on Impact Monitoring of Agricultural Pesticides. Rome: FAO, 61-76.

Waller, B.G. Water-Quality Characteristics of Everglades National Park, 1959-77, With Reference to the Effects of Water Management. Springfield, VA: National Technical Information Service PB82-228941.

Wauchope, R.D. (1978) "The pesticide content of surface water draining from agricultural fields -- a review." J. Environ. Qual., 7:459.

Weber, J.B. (1972) Interaction of organic pesticides with particulate matter in aquatic and soil systems." In: Fate of Organic Pesticides in the Aquatic Environment, S.D. Faust, ed. Washington DC: American Chemical Society, 55.

Weir, D. (1986) The Bhopal Syndrome: Pesticide Production and the Third World. Penang, Malaysia: International Organization of

Consumers Unions.

Woodwell, G.M. (1970) "Effects of pollution on the structure and physiology of ecosystems." Science, 168: 429-433.

World Bank. (1985) Guidelines for the Selection and Use of Pesticides in Bank Financed Projects and Their Procurement When Financed by the Bank. Washington, D.C.: World Bank.

World Bank. (1987) Wildlands: Their Protection and Management in Economic Development. Washington, D.C.: World Bank.

Yunus, A. and Lim, G.S. (1971) "A problem in the use of insecticides in paddy fields in West Malaysia: a case study." Malaysian Agricultural Journal, 48: 168-178.

Zitco, V. (1980) "The analysis of aquatic sediments for organic compounds." In: Contaminants and Sediments, Vol. 2, R.A. Baker and A. Arbor, eds. Ann Arbor, Mich: Ann Arbor Science, p. 89.

APPENDIX A

Relative toxicity of selected chlorinated hydrocarbon insecticides to rainbow trout and fathead minnow[31]

Insecticide	*Acute LC_{50} in mcg/L*	
	Rainbow Trout	*Fathead Minnow*
Chlordane	44	56
DDT	7	19
Dieldrin	10	16
Endrin	0.6	1.0
Heptachlor	19	56
Lindane[a]	27	67
Methoxychlor	62.6	7.5
Toxaphene[b]	11	14

[a]Lindane has been prescribed for removal of copepod parasites from fishes

[b]Toxaphene has been used as a piscicide

Relative 96-hour TL_m of DDT and endrin to four salmonid species[99]

Fish Species	*DDT (mcg/L)*	*Endrin (mcg/L)*
Rainbow trout	1.72	0.40
Cutthroat trout	1.37	0.19
Brook trout	11.90	0.59
Coho salmon	18.65	0.77

Acute toxicity of some herbicidal compounds to fishes[17,31,48,79]

Herbicide	*Fish Species*	*Acute Toxicity (mg/L)*	*LC_{50} Time (hr)*
Aqualin	Bluegill	0.08	24
	Brown trout	0.024	24
Dacthal	Bluegill	700.0	48
Dalapon (sodium)	Bluegill & fathead minnow	290.0	96
Dicamba	Bluegill	20.0	48
Dichlobenil	Bluegill	20.0	48
Diquat	Bluegill	350	96
	Largemouth bass	7.8	96
	Rainbow trout	11.2	96
2,4 D	Fathead minnow	5.6	96
Endothal (sodium)	Bluegill	120	96
	Fathead minnow	110	96
	Largemouth bass	120	96
Hydrothal Plus	Bluegill	3.5	48
Silvex	Bluegill	1.1	48

Selected tables showing acute toxicity of some pesticides to fishes (from Post, 1983, p. 235-38)

Acute toxicity of selected organophosphate insecticides to some fish species[3,51]

Compound Name	*Fish Species*	*96-hr LC_{50} (mg/L)*
Diazinon	Fathead minnow	7.8
	Brook trout	0.77
	Bluegill	0.46
Dursban®	Rainbow trout	0.011
Fenthion® (Baytex)	Fathead minnow	2.4
	Largemouth bass	1.54
	Rainbow trout	0.93
Guthion®	Fathead minnow	0.093
	Largemouth bass	0.005
	Rainbow trout	0.014
Methylparathion	Fathead minnow	8.9
	Largemouth bass	5.22
	Rainbow trout	2.75
Malathion	Fathead minnow	9.0
	Largemouth bass	0.285
	Rainbow trout	0.17
Parathion	Fathead minnow	1.6
	Largemouth bass	0.19

Percent residual brain AChE activity versus activity index and time for recovery of normal AChE activity in three salmonid species following contact with sublethal amounts of malathion[38]

Malathion Concentration (mcg/L)	*Residual Brain AChE (%)[a]*	*Activity Index (Time)*	*Activity Index (%)[a]*	*Time for Complete AChE Recovery (days)[a]*
Brook trout:				
0	100.0[c]	29:18[b]	100.0	
40	68.4	24:31	83.7	
90	51.4	16:15	55:5	
120	24.3	8:35	29.3	25
Rainbow trout:				
0	100.0[d]	35:20	100.0	
55	81.5	34:12	97.7	
112	50.6	23:15	66.3	
175	28.1	13:26	29.0	35
Coho salmon:				
0	100.0[e]	43:06	100.0	
100	71.9	41:07	95.4	
200	52.0	33:03	76.7	
300	29.0	20:58	48.7	42

[a]Compared to nontreated fish of the same species
[b]Minutes:Seconds
[c]Percent residual AChE obtained in 7 days exposure
[d]Percent residual AChE obtained in 10 days exposure
[e]Percent residual AChE obtained in 9 days exposure

APPENDIX B

Taxa	Orchards		Pastures 5 months during 1980***
	1951—1957*	1978—1980**	
Porifera	1	0	0
Platyhelminthes			
Tricladida	4	5	5
Ectoprocta	2	1	1
Annelida			
Oligochaeta	7	7	6
Hirudinea	10	7	8
Mollusca			
Gastropoda	20	20	22
Bivalva	3	1	5
Arachnida			
Acari	18	1	11
Araneae	3	4	4
Crustacea			
Cladocera	6	6	6
Copepoda	13	11	11
Branchiura	1	0	0
Isopoda	1	1	1
Decapoda	1	0	0
Insecta			
Collembola	3	4	4
Ephemeroptera	5	2	3
Odonata	14	5	9
Heteroptera	16	12	11
Neuroptera	1	0	1
Lepidoptera	3	2	2
Trichoptera	7	0	3
Coleoptera	62	14	45
Diptera ..	10	41	36
Chordata (except Aves)	14	15	10

*As modern pesticides were being introduced (Garms 1961).
**After about 25 years of intensive pesticide use (Heckman 1980).
***No pesticides applied (preliminary results only).

FIGURE B-1: Number of species of various taxa of macrofauna in drainage ditches in West Germany (from Heckman, 1982, p. 437).

The taxa marked with (+) are expected to show major losses after the long-term use of pesticides. Prediction is based on results obtained in Northern Germany (Heckman 1980). Taxa with predators important for pest control are marked (!)

Major taxa	Species obsreved* 1975-76	Effect expected from pesticides
Chidaria	1	—
Annelida		
Oligochaeta	6	—
Hirudinea !	5	—
Mollusca		
Gastropoda	12	—
Arachnida		
Acari!	4	+
Araneida!	2	—
Crustacea		
Branchiopoda	19	—
Copepoda	3	—
Branchiura	1	—
Isopoda	1	—
Amphipoda	1	—
Decapoda	2	—
Insecta		
Collembola	1	—
Ephemeroptera	1	—
Odonata !	21	+
Heteorptera !	15	—
Coleoptera !	33	+
Lepidoptera	1	—
Hymenoptera !	5	—
Diptera	29	—
Chordata		
Pisces !	18	—
Amphibia !	6	—
Reptilia	4	—

FIGURE B-2: Major macrofauna in a rice field in Northeastern Thailand during 1975-1976 (from Heckman, 1982, p. 439).

APPENDIX C

= Density reduced by more than 50%, - Density reduced by less than 50%,
+ Density increased, +/- Variable response.

	Acari	Collembola	Carabidae	Pauropoda	Diplopoda	Symphyla	Nematoda	Lumbricidae	Enchytraeidae	Mollusca
ORGANOCHLORINES										
Aldrin	-	-	■	■	■	■	+/-			-
Chlordane	-	-	■	-				■		
Dieldrin	-	-	■		■					
DDT	■	+	■	■	■	■	+/-	-		
Endrin	-	-			-			■		
Heptachlor	-	-	■				+/-	-	-	
HCH	-	■	■		■	■	+/-			
Isobenzan	■	■						-		
ORGANOPHOSPHATES										
Chlorfenvinphos	-	+		■						
Chlorpyrifos	-	-					-	-		
Demeton		-								
Diazinon	+/-	+	■	■	-	-	-			
Disulfoton	+/-	+/-	■	■		-				
Fenitrothion		-								
Fensulfothion		-	-				■	■		
Fenthion		-								
Fonofos			-							
Malathion						-		■	■	
Menazan		-								
Parathion	-	+/-	■	■	■	■	-			-
Phorate	-	-	■	■		-	-	■	+	-
Thionazin	+/-	+/-					-			
Trichlorfon		+				-		-		
CARBAMATES										
Aldicarb	■	■					■	-	■	
Carbaryl	■	■	■		■		-	■		-
Carbofuran	-	-					■	■		
Methiocarb										■

References

Sheals 1956, Raw 1965, Edwards 1965, 1974, 1977, 1980, 1983, Edwards, Dennis and Empson 1967, Edwards, Thompson and Lofty 1967, Fox 1967, Griffiths et al. 1967, Davis 1968, Edwards et al. 1968, Kelsey and Arlidge 1968, Voronova 1968, Way and Scopes 1968, Thompson 1971, Thompson and Gore 1972, Edwards and Thompson 1973, 1975, Wibo 1973, Tomlin and Gore 1974, Martin 1975, Brown 1977, Breslin 1979, Broadbent and Tomlin 1980, Hoy 1980.

FIGURE C-1: Responses of soil invertebrates to some commonly used insecticides (from Curry, 1986, p. 378)

+ positive - negative o neutral +/- variable () slight effect

	Temperature	Moisture content	Porosity/ aeration	Organic matter	Microbial Activity	Microfaunal Activity	Mesofaunal Activity	Macrofaunal Activity	Decomposition Rate
GRASSLAND									
Mowing	+	-	o	-	+	o	-	+	+
Grazing	+	-	-	-	+	o	-	+	+
Inorganic fertilizers	o	o	o	-	+	(+)	(-)	+/-	+
Organic fertilizers	-	+	o	+	+	+	+	+	+
Burning	+	-	o	-	+	-	-	-	+
Irrigation	-	+	o	o	+	+	+	+	+
Drainage	+	-	+	-	+	+	+	+	+
ARABLE LAND									
Plowing	+	-	+	-	+	+/-	-	-	+
Minimum cultivation	(+)	(-)	-	(-)	(+)	o	(-)	(-)	(+)
Inorganic fertilizers	o	o	o	-	+	+	(+)	(+)	+
Organic fertilizers	-	+	o	+	+	+	+	+	+
Surface crop residues	-	+	o	+	+	(+)	(+)	+	(+)
Incorporated residues	(-)	(+)	o	+	+	+	(+)	(+)	+
Residue removal	+	-	o	-	-	-	-	-	-
Herbicides	o	o	o	o	(-)	o	o	o	(-)
Fungicides	o	o	o	o	-	o	o	(-)	-
Fumigants	o	o	o	o	-	-	-	-	-
Insecticides	o	o	o	o	o	-	-	-	-
Heavy metals	o	o	o	o	-	-	-	-	-

FIGURE C-2: General responses of some soil biotic and abiotic parameters to management (from Curry, 1986, p. 384).

APPENDIX D

Surface films (sprayed on water surface)	kerosene, diesel oil, fuel oil No. 2, Flit MLO, monomolecular organic surface film of isosteryl alcohol.
Copper arsenite	Paris Green
Chlorinated hydrocarbons	DDT, dieldrin, chlordane, endrin, lindane (BHC), heptachlor, methoxychlor. All have been discontinued for control of biting marsh dipterans, with the exception of methoxychlor.
Organophosphates (cholinesterase inhibitors)	malathion, parathion, fenthion (Baytex), trichlorfon, fenitrothion, chlorpyrifos (Dursban), diazinon, naled (Dibrom), temephos (Abate).
Carbamates (cholinesterase inhibitors)	propoxur (Baygon), carbaryl (Sevin).
Botanicals	pyrethrum (insecticidal compound from the flowers of chrysanthemums); synthetic pyrethroids (resmethrin, permethrin). Pyrethrins are sometimes used with a synergist such as piperonyl butoxide.
Insect growth regulators (IGRs)	methoprene (Altosid), a juvenile hormone mimic; diflubenzuron (Dimilin), a chitin inhibitor.
Toxin-producing bacterial spores	*Bacillus thuringiensis* var. *israelensis* (Serotype H-14), commonly known as BTI (Bactimos, Teknar); *Baccilus spaericus*.

FIGURE D-1: Insecticides that are used, or have been used, for the larviciding and/or adulticiding of biting dipterans (mosquitoes, tabanids, gnats) in or near tidal marshes (from Daiber, 1986,p.179).

Study	*Location*	*Insecticide Used*	*Application Rate*	*Impacted Organism*	*Adverse Effect Observed*
Rio (1970)	Laboratory, New Jersey	Abate	0.4 to 8 mg/l	Fiddler crab	No immediate effect for first 2 days. By day 4 increasing mortality with increasing concentration.
Campbell & Denno (1976)	Field, New Jersey	Abade, Dursban		Marsh community	Selective mosquito larvicide. No significant change in diversity, richness, or density of nontarget salt marsh insect community.
Ward and Busch (1976)	Laboratory, New Jersey	Abate	ppm	Fiddler crab	24-hour LC 50 at 9.12 ppm. at 4.13 ppm, crabs either killed or eliminated escape response in 50% of animals tested.
Fitzpatrick and Sutherland (1978)	Field, New Jersey	Abate, Dursban	Repeated applications	Coffee-bean snail	No significant change in snail densities when subjected to granular form. Temporary significant depression of snail densities when Abate used in an emulsion.
Butler et al. (1960)	Laboratory, Florida	Chlordane DDT Dieldrin Endrin Sevin Toxaphene	0.01 ppm 0.1 ppm 0.1 ppm 0.1 ppm 1.0 ppm 0.1 ppm	Oyster	Sublethal inhibition of shell growth after 24-hr exposure.
Croker and Wilson (1965)	Field, Florida	DDT	0.2 lb/acre	Fish and shrimp	Significant fish and *Palaemonetes* mortalities soon after application.
Harrington & Bidlingmayer	Field, Florida	Dieldrin	1.0 lb/acre	Fish and invertebrates	Significant fish and invertebrate mortalities.
Christiansen *et al.* (1978)	Laboratory, North Carolina	Dimilin (insect growth regulator)	0.5, 1, 3, 5, 7, and 10 ppb	Larvae of mud crab *Rhithropanopeus harrisii*, and *Sesarma riticulatum*	Survival of larvae of both species decreased with increased concentration of Dimilin.
Hansen (1969)	Laboratory, Florida	Endrin	ppm	Sheepshead minnow	24-hour LC 50 at 0.003 ppm.
Katz (1961)	Laboratory, Oregon	Lindane	ppb	Stickleback	Estimated 96-hr TLm for 5‰ was 44 ppb
Hansen (1969)	Laboratory, Florida	Malathion	ppm	Sheepshead minnow	24-hr LC 50 at 0.3 ppm
Rio (1970)	Laboratory, New Jersey	Malathion	8 to 16 mg/l	Fiddler crab	No survival at day 1 in 16 mg/l, no survival at day 3 in 12 mg/l, only 20% survival by day 3 in 8 mg/l with increasing mortality to days 7 and 8 with 5% survival.
Butler (1963)	Laboratory, Florida	Sevin	ppm	Long nose killifish	24-hr LC 50 at 1.75 ppm
Stewart *et al.* (1967)	Laboratory, Oregon	Sevin	ppm	Stickleback	24-hr LC 50 at 6.7 ppm
Hansen (1969)	Laboratory, Florida	Sevin	ppm	Sheepshead minnow	24-hr LC 50 at 2.8 ppm
Katz (1961)	Laboratory, Oregon	Toxaphene	ppb	Stickleback	96-hr TLm at 5‰ was 8.6 ppb

Note: LC 50 Lethal concentration, 50% mortality
TLm Median tolerance Limit

FIGURE D-2: Representative list of insecticides and any adverse consequences resulting from their use in tidal marshes or with selected animals characteristic of that habitat (from Daiber, 1986, pp. 192-183).